Advanced Web Security

Anonymity

Anonymity on Internet

- Some degree of anonymity from using pseudonyms
- However, anonymity is always limited by IP address
  - TCP will reveal your IP address
  - IP address together with ISP cooperation → Anonymity is broken
  - We do not assume that the ISP will keep our identity secret
    - In any case, we are not anonymous to the ISP
- Assumption: If we know IP address, we know identity

Usage of Anonymity

Pros
- Discussion of sensitive and personal issues
- Information searches
- Freedom of speech in intolerant environments
- Polls/Surveys
- Counceling for drug or alcohol abuse
- Criminal victims
- Snitches and rats

Cons
- Accusations
- Propaganda
- Spreading of copyright protected material
- Other illegal acts

We just focus on the technology

Anonymous communication properties

- **Sender anonymity** – The identity of the party sending the message is hidden
- **Receiver anonymity** – The identity of the (actual) receiver of the message is hidden
- **Unlinkability of sender and receiver** – Two parties can not be identified as communicating with each other
- **Sender activity** – the fact that a sender is sending something
- **Receiver activity** – the fact that the receiver is receiving something
- **Sender content** – the sender sent a particular content
- **Receiver content** – the receiver received a particular content

Traffic analysis problem

- The problem of keeping confidential who is talking to whom and when they talk
- Can also be used to identify which type of data is sent even if data is encrypted

- Related problem: traffic confirmation problem – the problem of deciding if two given peers are communicating at a certain time
  - Very difficult to protect against

Anonymity

- You can only be anonymous within a set of other users
- More people using the system → more anonymity is possible
- Anonymity set – The set of people in which you are anonymous
  - Large set can provide higher anonymity than small

Anonymity Solutions

- Two main categories
  - High-latency designs → There is a significant delay between sending and receiving a message
    - Mixmaster
    - Babel
    - Mixminion
  - Low-latency designs → Aims at minimizing the time between sending and receiving a message
    - Tor
    - Java anon proxy
    - Freedom

The Global Passive Adversary (GPA)

- An adversary that can observe every node in the network
- A very strong adversary
- Typically
  - Low-latency designs cannot protect against the GPA
  - High-latency designs aims at protecting against the GPA

Anonymity

- First anonymity system:
  - D. Chaum, 1981
- Allowed *anonymous encrypted* email (hiding the address of the sender)
- Uses *public key cryptography*
- Based on a *Mix*

Assumptions

- Security assumption
  - It is not possible to find the correspondence between plaintext and ciphertext
- Power of adversary
  - Anyone can learn origin and destination of any and all messages in the underlying communication system
  - Anyone may inject, modify or remove messages

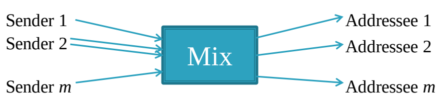
The Mix

- Purpose: Hide the correspondence between input and output items
- Computer that process each item
  - Can perform cryptographic operations
  - Reorders incoming items
- High latency – many inputs must be collected before output is produced to avoid timing attacks
- Make sure no item is processed more than once
  - Otherwise sender can be identified

Duplicating an Item

- If one item is duplicated at both input and output we know the correspondence between that sender and addressee

Sender 2 sent message to Addressee 1!



Duplicate message deleted by Mix

Sending a Message

- Prepare a message M to send to A:
  1. Add randomness R_0 to message in order to avoid simple guessing attacks
  2. Encrypt message using A's public key
  3. Add address of receiver together with randomness R_1
  4. Encrypt with public key of Mix
- Process data in Mix
  1. Decrypt data using private key of Mix
  2. Remove R_1
  3. Identify receiver A and forward encrypted message to A
- Read message at Receiver
  1. Decrypt message with receiver's private key

$$K_1(R_1, K_a(R_0, M), A) \longrightarrow \boxed{\text{Mix}} \longrightarrow K_a(R_0, M), A$$

Return Address

- Allow addressee to return message to sender without revealing return address
- Include untraceable return address

$$K_1(R_1, A_x), K_x$$

A_x – Return address used by addressee
K_x - Temporary public key used by addressee
R_1 - Random string also used as key by Mix

- Message returned to sender and processed by Mix

$$A_x, R_1(K_x(R_0, M)) \longleftarrow \boxed{\text{Mix}} \longleftarrow K_1(R_1, A_x), K_x(R_0, M)$$

Using Several Mixes

- Use cascade of *n* mixes – only one needs to be honest
- Prepare message for *n* Mixes

$$K_n(R_n, K_{n-1}(R_{n-1}, \ldots, K_2(R_2, K_1(R_1, K_a(R_0, M), A_y)) \cdots))$$

- Message exiting first Mix

$$K_{n-1}(R_{n-1}, \ldots, K_2(R_2, K_1(R_1, K_a(R_0, M), A_y)) \cdots)$$

- Message exiting last Mix

$$K_a(R_0, M), A_y$$

Sender *x* → Mix → Mix → - - - - → Mix → Addressee *y*

First Mix K_n … Last Mix K_1

Several Mixes with Return Address

- Untracable return address prepared as

$$K_1(R_1, K_2(R_2, \ldots, K_{n-1}(R_{n-1}, K_n(R_n, A_x)) \cdots))$$

- Returned together with message

$$K_x(R_0, M)$$

- Output of first mix

$$K_2(R_2, \ldots, K_{n-1}(R_{n-1}, K_n(R_n, A_x)) \cdots), R_1(K_x(R_0, M))$$

- Output of last Mix

$$A_x, R_n(R_{n-1}(R_{n-2} \ldots R_2(R_1(K_x(R_0, M))) \cdots))$$

Sender *x* ← Mix ← Mix ← - - - - ← Mix ← Addressee *y*

Last Mix K_n … First Mix K_1

Attacks on Mixes

- Message size
  - Problem: If the size of the messages are different then it is easy to correlate inputs and outputs
  - Solution: Pad all packets to the same size
- Replay attack
  - Problem: Replaying an old message will send it to the same place as before
  - Solution: Save a fingerprint of ALL messages, or use time stamps
- N–1 attack
  - Problem: If an adversary controls all messages going into the Mix except the target message, then it is easy to see where the target message is going
  - Solution: Make sure all packets come from different senders (Will at least make this attack more difficult)

The Long-Term Intersection Attack

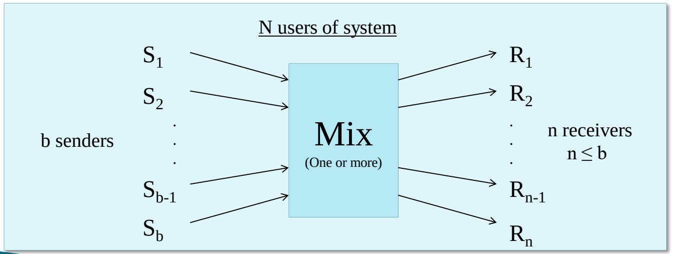
- Generic attack, works even when Mixes are perfect
- Assumption
  - Adversary can observe all messages entering and leaving the mix network
  - Adversary has good chance of guessing when a message entering the network is likely to leave
- Assume messages can be linked to same sender
  - Mailing list or forum pseudonym
  - Consecutive messages in conversation
- Store a list of possible senders at time i, i+1,i+2,....
- Intersect lists → right sender will be left in list
- Problem: The anonymity set is different in each time instance

Possible Countermeasures

- Remove linkability
  - Wait for later batches
  - Sometimes difficult or impossible
- Send dummy traffic from as many users as possible
  - Will increase the anonymity sets
  - Not possible with offline users

Disclosure Attack

- Kedogan, Agrawal and Penz, 2002
- Generic attack, similar to the intersection attack
- Assume all senders are different
- Alice has *m* communication partners, reveal these!



Disclosure Attack

Learning phase

- Attacker records all receivers used when Alice is sender at time *t* in set R_t
- This is done until we have *m* mutually disjoint sets $R_1,...R_m$

$$\forall i, i \neq j, R_i \cap R_j = \emptyset$$

- *Now we know that each set includes a communication partner of Alice*

Disclosure Attack

Excluding phase

- Take new set R
  - If
  $$R \cap R_i \neq \emptyset \text{ and } R \cap R_j = \emptyset \quad \forall j \neq i$$
  - Then replace R_i by $R_i \cap R$
- Decrease set size until all m sets contain only one recipient → these m recipients are Alice's communication partners
- Conclusion: A Mix is insecure if $m \leq \lfloor N/n \rfloor$

General Problem

- High-latency design might be ok for email
- For interactive use such as HTTP, low latency is required

Onion Routing

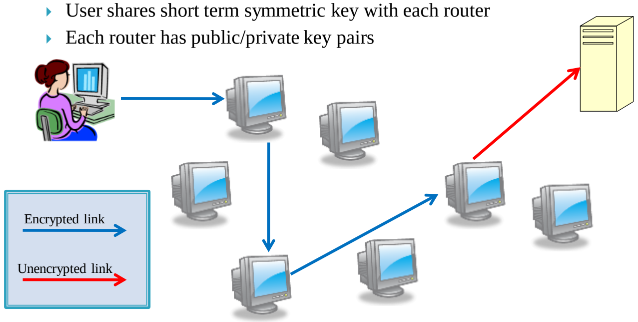
- Basically a set of real-time Chaum Mixes
  - One Mix is not enough in real-time since timing attacks will be ”easy”
  - Anonymity set is necessarily small
  - On the other hand, real-time allows for e.g., HTTP based traffic, voice over IP, etc
- Improving protection
  - Many Mixes
  - Large volumes of traffic
  - Synthetic traffic
  - All packets arriving within some small fixed time interval is mixed

Tor – The Onion Router

- Dingledine, Mathewson and Syverson, 2004
- Originally sponsored by US Naval Research Laboratory
- Now funded by Tor Project, a non-profit organization
- Low latency – appropriate for real-time traffic like HTTP
- Because of the low latency requirement we do not want each ”Mix” to decrypt the message using a private key
  - Symmetric cryptography is much faster

Tor Network

- User connects to remote server through several onion routers
- Each (blue) link is encrypted with TLS
- User shares short term symmetric key with each router
- Each router has public/private key pairs



Data Transmitted in Cells

- Each cell is 512 bytes
- Two types of cells
  - Control cells – always interpreted by receiving node
    - Padding
    - Create, Created
    - Destroy
  - Relay cells – Interpreted by last cell, relayed by other cells
    - Relay begin
    - Relay data
    - Relay extend
    - ...

Control Cells and Relay Cells

Bytes	Control cell
2	CircID
1	CMD
509	DATA

Bytes	Relay cell
2	CircID
1	CMD
1	Relay CMD
2	Recognized
2	StreamID
4	Digest
2	Length
498	DATA

- CircID – Hold a 2-byte ID for the connection to the next router
- CMD – command to determine what to do
- Recognized – used to know if packet should be relayed or interpreted
- StreamID – ID for this stream
- Digest – Integrity check
- Length – bytes in DATA that is real data

Negotiating Symmetric Key with First Node

- Diffie-Hellman key exchange

Alice → OR_1: $\mathrm{ID}_1, \mathrm{Create}, K_{OR_1}(g^{x_1}) \mod p$

OR_1: $K_1 = (g^{x_1})^{y_1} \mod p$

OR_1 → Alice: $\mathrm{ID}_1, \mathrm{Created}, g^{y_1} \mod p, H(K_1)$

Alice: $K_1 = (g^{y_1})^{x_1} \mod p$

- Unilateral entity authentication – Alice knows she is handshaking with OR_1, but OR_1 does not know who is opening the circuit.
- Unilateral key authentication – Alice knows that only OR_1 knows the shared key K_1.

K() – Public key encryption (asymm)
K{} – Secret key encryption (symm)

Negotiating Symmetric Key with Second Node

- Contact second node through first node

Alice → OR_1: $\mathrm{ID}_1, \mathrm{Relay}, K_1\{\mathrm{Extend}, OR_2, K_{OR_2}(g^{x_2})\}$

OR_1 → OR_2: $\mathrm{ID}_2, \mathrm{Create}, K_{OR_2}(g^{x_2})$

OR_2 → OR_1: $\mathrm{ID}_2, \mathrm{Created}, g^{y_2}, H(K_2)$

OR_1 → Alice: $\mathrm{ID}_1, \mathrm{Relay}, K_1\{\mathrm{Extended}, g^{y_2}, H(K_2)\}$

- OR_1 keeps track of mapping between ID_1 and ID_2
- Alice do not need any info about ID_2

K() – Public key encryption (asymm)
K{} – Secret key encryption (symm)

Constructing Circuit

- OR only knows about node before and after.
  - ID is used to identify where to send packets
  - Table is kept to identify where incoming packets are going
- User changes to new circuit periodically (about once per 10 minutes)
- Setup requires public key operations
  - Takes time
- Users construct circuits preemptively

Relaying Data Through Nodes

Alice, OR_1, OR_2, Website

Alice → OR_1: $\mathrm{ID}_1, \mathrm{Relay}, K_1\{K_2\{\mathrm{Begin}, \mathit{website}\}\}$

OR_1 → OR_2: $\mathrm{ID}_2, \mathrm{Relay}, K_2\{\mathrm{Begin}, \mathit{website}\}$

OR_2 ↔ Website: *TCP Handshake*

OR_2 → OR_1: $\mathrm{ID}_2, \mathrm{Relay}, K_2\{\mathit{Connected}\}$

OR_1 → Alice: $\mathrm{ID}_1, \mathrm{Relay}, K_1\{K_2\{\mathit{Connected}\}\}$

Alice → OR_1: $\mathrm{ID}_1, \mathrm{Relay}, K_1\{K_2\{\mathit{Data}, \text{"..."}\}\}$

OR_1 → OR_2: $\mathrm{ID}_2, \mathrm{Relay}, K_2\{\mathit{Data}, \text{"..."}\}$

OR_2 → Website: "..."

128 bit AES in counter mode is used

K() – Public key encryption (asymm)
K{} – Secret key encryption (symm)

Determine when to Relay and when to Interpret

2	CircID
1	CMD
1	Relay CMD
2	**Recognized**
2	StreamID
4	**Digest**
2	Length
498	DATA

Relay cell

- Control cells are always interpreted
- Relay cells are interpreted by exit node
- Recognized field set to zero and digest calculated with SHA-1 by initiator before encrypted with $K_n, \ldots, K_2, K_1$
- After decryption at OR_i these 6 bytes are checked. If OK, then interpret, otherwise relay
- Probablity of failure: 2^{-48}
- Leaky pipe circuit – Allow exit at different ORs in same circuit

Tor Security

- Tor does not claim to protect against
  - A Global Passive Adversary – someone who can observe all network links
  - Traffic confirmation attacks
- Almost no mixing because of real time
- Is the Global Passive Adversary realistic?
  - Maybe not, but an attacker does not really have to observe everything.
  - A real world observer can instead be adaptive – select where to observe based on prior information
- Users running their own router has higher anonymity

Perfect Forward Secrecy

- If private key of a router is compromised, the session key can still not be derived
  - Property of Diffie-Hellman Key exchange

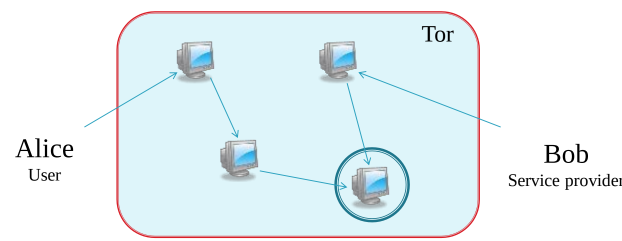
$$\xrightarrow{\mathrm{ID}_1, \mathrm{Create}, \boxed{K_{OR_1}}(g^{x_1}) \mod p}$$

$$\xleftarrow{\mathrm{ID}_1, \mathrm{Created}, g^{y_1} \mod p, H(K_1)}$$

- Implication: If encrypted traffic is recorded, and session keys are destroyed, it can never be decrypted even if long-term keys are stolen
- Compare to the case when the client e.g., generates a session key and encrypts it with router's public key → no perfect forward secrecy

Hidden Services

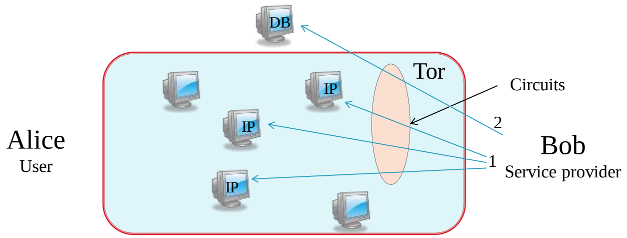
- Anonymous services (hidden services), e.g., anonymous webserver
- How can we provide a service through a web server without revealing our IP?



Using Rendezvous Points

Bob initializes service

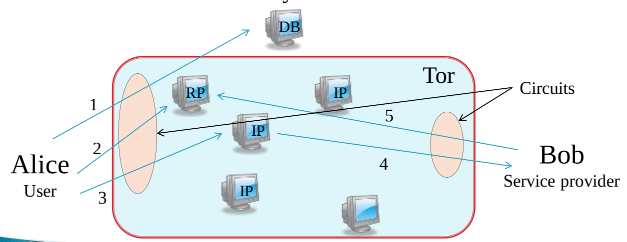
- Bobs service identified by his public key
- Bobs chooses a set of introduction points (IP)
- Bob builds circuit to each introduction point
  - ”Public key” can be found at IP_A, IP_B, IP_C, ... is written in database



Using Rendezvous Points

Alice wants to use Bobs service

- Alice finds IPs to Bob in database
- Alice chooses OR as rendezvous point (RP) and connects to it
- Alice connects to one of Bobs IPs and tells it about her RP
- Introduction point forwards message to Bob and Bob can connect to the RP chosen by Alice



Difference Between Anonymity and Encryption

- Tor does not provide end-to-end encryption
- Owner of exit node decrypts traffic and forwards it in plain text
- Identifying information in data stream can still reveal your identity
  - If you log in to an email account
  - If you pay with your credit card
  - If you send instant messages
- Sept 2007, 100 email accounts from embassies and government agencies posted on internet
  - Tor exit node was used to capture the info
  - Probable chain of events: Stolen accounts → Use Tor to hide who you are → End node sees the traffic