Anonymous Web Browsing

Software Security

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Objectives of today's lecture

- ➜ Repetition – definitions of *anonymity* and classification of *remailers*
- ➜ Understanding the principles of *anonymisation services*
- ➜ Reflecting the *differences between TOR and JAP*
- ➜ Being able to reproduce two *protocols for the most important use cases* of TOR

What exactly do we mean by anonymity?

Definition (given by Pfitzmann)

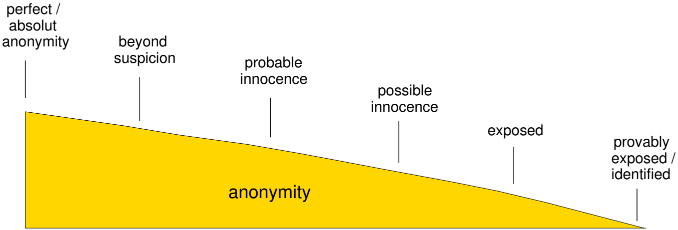
A person in a role R is anonymous relative to an event E and an attacker A, if for every person not cooperating with A, the anonymous person has the role R in E with a probability truly greater than 0 and truly smaller than 1 after every observation from A.

What exactly do we mean by perfect anonymity?

Definition (given by Pfitzmann)

A person in a role R relative to an event E and an attacker A is perfectly anonymous, if for every person not cooperating with A the anonymous person has the role R in E with the same probability before and after an observation from A.

Other Definitions (Degrees) of Anonymity



Source: M. Reiter, A. Rubin: *Crowds: Anonymity for Web Transactions*, 1999.

- **Beyond suspicion**

  $\rightarrow$ no more likely than any other potential sender

- **Probable innocence**

  $\rightarrow$ no more likely to be the sender than not to be the sender

- **Possible innocence**

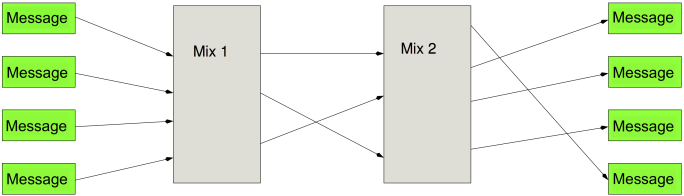
  $\rightarrow$ there is a nontrivial probability that the real sender is someone else

Strategies for Anonymization

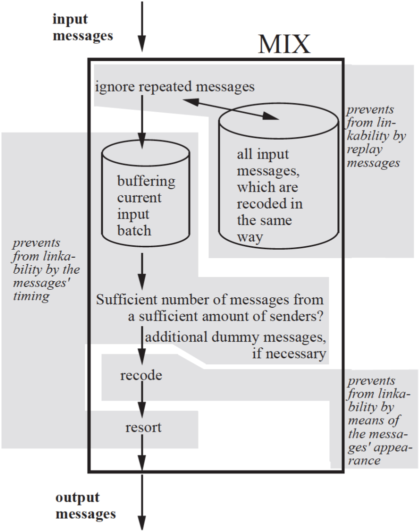
What is a Mix server?

Basic idea of mixing according to [Chaum, 1981]

- Provides unlikability between incoming and outcoming messages
- Mixes collects messages, changes their coding and forward them in different order



Basis Functions of a Mix server?



Source: A. Pfitzmann: Script – *Security in IT-Networks*, 2012

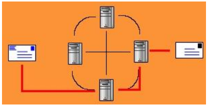
What **types of remailers** do you know?

Classification

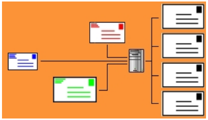
- Pseudonymous remailers (**Type 0**)
- Cypherpunk remailers[1] (**Type I**)
- Mixmaster remailers (**Type II**)
- Mixminion remailers (**Type III**)

Type 0

Type I



Type II



➜ And what else can the **Type III** mailers do?

[1] *Cypherpunk* is an artificial word derived from cipher, cyber and punk

What other anonymization services do exist?

Problem

- Remailers have *too long response* times
- Applications such as web browsing require low latency
- Approach of remailers (use of MIXes as brokers between users and service providers) have to be transferred to other protocols

Software (Selection)

- Anonymization Proxy
- Jondos (formerly JAP, Java Anon Proxy)
- Tor (The Onion Router)

Simple Solution with a Proxy

Idea

- Put a proxy server in between, via which all users must access the Web services
- Servers that offer services only see the IP address of this proxy server

Problem

- Data needed for de-anonymization is located on this proxy server
- Users must blindly trust the proxy server

Better Solution with Jondos/JAP

Idea

- Routing messages over more than one Mix server, communication will be encrypted

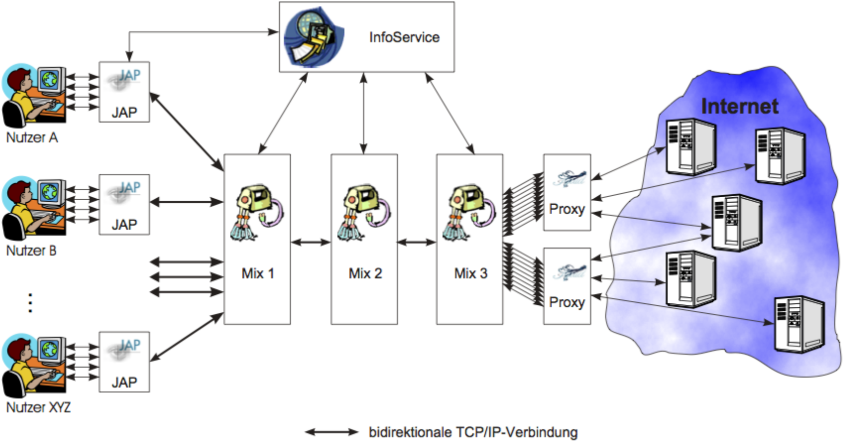
Example with three MIX-es

1. Initiator sends a request to *Mix1* server, *Mix1* can see that the data came from the Initiator
2. Forwarding the data to *Mix2*, *Mix2* can only see that the data came from *Mix1*
3. Forwarding the data to the *Mix3* server, which can only see that the data came from *Mix2*
   ➜ finally *Mix3* sends a request to the web server

Assumption

- Providers of the three MIXes do not work together, e.g. by a self-commitment of the providers

Architecture of Jondos/JAP



Source: S. Köpsell: AnonDienst - Design und Implementierung, 2004, http://anon.inf.tu-dresden.de

Solution with Tor

Idea

- Distributed anonymous network

Properties of Tor

- Mix servers are not only provided by official providers
- *Each person* is authorized to contribute their own node for the Tor network
- System automatically searches for available mix servers

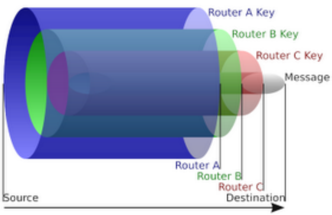
Problems

- Organization could offer a large number of nodes and thus the ability to control the entire network
- Browsing speed decreases significant when using Tor
- Last step *Mix N* $\rightarrow$ Web Server is unencrypted by default

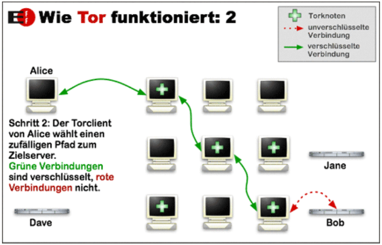
Tor: The Onion Router

Idea

- Use of a multi-layer encryption scheme
- Number of nodes to be used can be set individually by the user



Source: *http://en.wikipedia.org/wiki*



Source: *http://www.torproject.org*

Differences between Jondos/JAP & Tor

Jondos/JAP

- Cascades: fixed chain of Mixes
- Only one Mix cascade can be selected as user
- Generation of artificial messages
- Fixed number of servers (approx. 16)
- Supports HTTP/HTTPS/FTP
- Good performance with commercial version

Tor

- Dynamically variable routes of Mixes: random selection
- User has no control
- No artificial message generation
- Open network, many servers (2018, approx. 6500)
- Software can only be used as SOCKS proxy
- Performance varies depending on the selected paths

Types of Tor Nodes

1. **Onion Proxy:** User client program to connect to the network
2. **Onion Router:** Server for forwarding anonymous connections (middle server and exit server)
3. **Entry Guard:** Onion router, which acts as an entry point for the Tor network
4. **Directory Service:** Provides essential information about other servers on the network
5. **Introduction Point:** Server is required for hidden services in order to receive a message from a service user as a service provider
6. **Rendezvous Point:** Server is also used for hidden services as an anonymous communication point between service provider and user
7. **Bridge Relays:** These servers are highly protected and are intended for use by people from censored Internet networks

Features of TOR

➜ Classification according to degree of anonymity for participants

1. Use of public services, whereby *only* the user should be anonymous
2. Offer and use hidden services, whereby *both* user and provider should be anonymous

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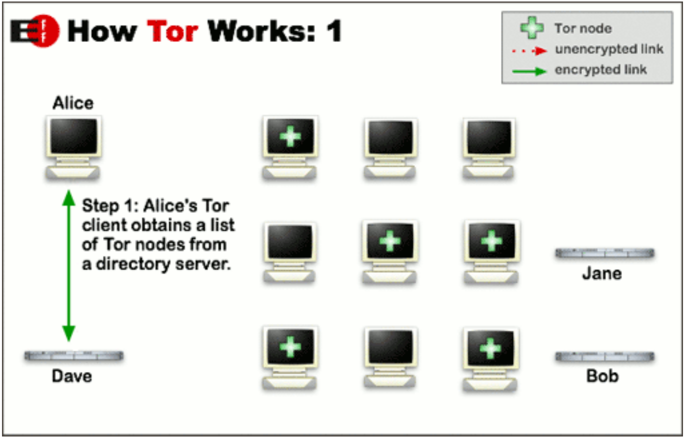
How to use public services anonymously?

Procedure

1. Alice defines the length of the routing (number of nodes) to the service and her client requests a list of Tor nodes from the directory server
2. Alice's client selects a random path to the service, taking into account the previously defined path length
3. The path is changed periodically for further requests to the service

Protocol Step 1

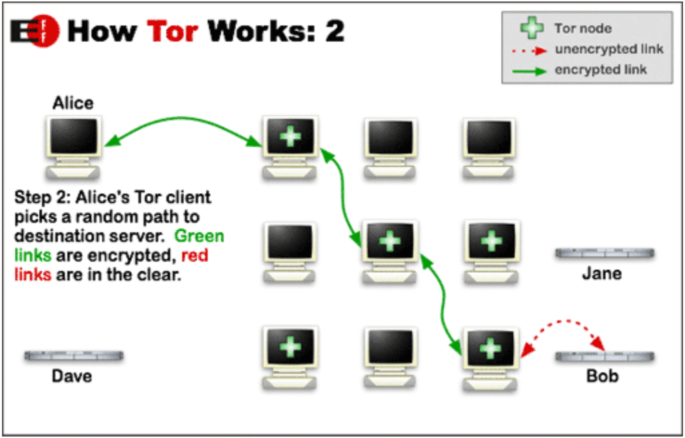
- Alice's client requests a list of Tor nodes from the directory server



Quelle: http://www.torproject.org

Protocol Step 2

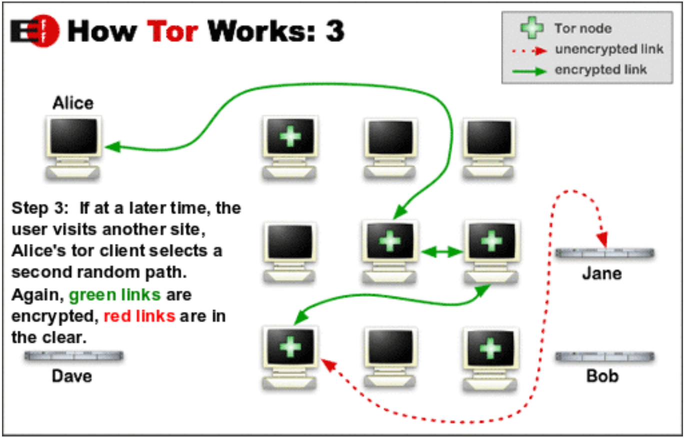
- ➜ Alice's client selects a random path to the service, taking into account the previously defined path length



Quelle: http://www.torproject.org

Protocol Step 3

- The path is changed periodically for further requests to the same or to other services

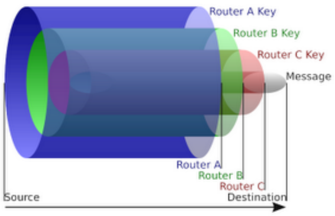


Quelle: http://www.torproject.org

Tor: The **Onion** Router

How it really works?

- Implementation of onion-like encryption by *symmetric encrypted channels* ➜ called: circuits
- Asymmetric cryptography is used for key exchange ➜ Diffie-Hellman Protocol



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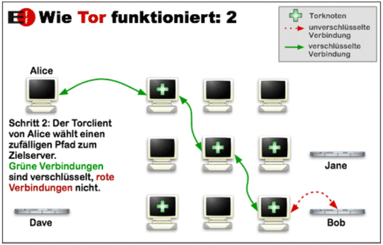


Quelle: *http://www.torproject.org*

Diffie-Hellman Key Exchange

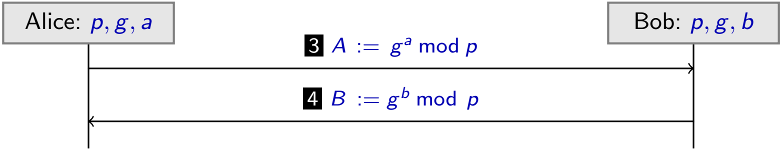
1. Choose p and g randomly, where p is a *prime number* and g is a *primitive root of unity* for $\mathbb{Z}_p^*$

   mit $\mathbb{Z}_p^* = \{a : \mathbb{Z}_p \mid gcd(a,p) = 1\}$ und $\mathbb{Z}_p = \{0, \ldots, p-1\}$

   ➜ p and g are public

2. Alice and Bob have to choose randomly a and b of $\mathbb{Z}_p$

   ➜ a and b are secret



5. Alice calculates $K := B^a \bmod p$ and Bob $K := A^b \bmod p$

   ➜ K is the key for the symmetric encryption

Repetition Number Theory

Properties of the Primitive Root of Unity

- Let p be a prime number with $\mathbb{Z}_p = \{0, \ldots, p-1\}$

  Then is g *primitive root of unity*, if $g \in \mathbb{Z}_p^*$
  and $\{1, \ldots, p-1\} = \{g^1, \ldots, g^{p-1}\}$

  ➜ The primitive root of unity g is also called *Generator* of $\mathbb{Z}_p \setminus \{0\}$

Correctness of the Generator

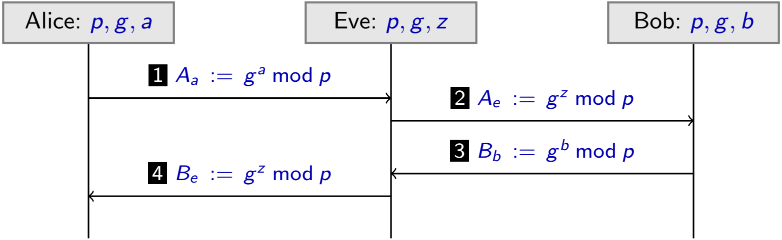
- Correctness of g can be proven efficiently if $p-1$ is factorizable

  ➜ if e.g. $p - 1 = 2 \cdot r$ and r is a prime number, so we have to prove that the following conditions are *not* satisfied

  $g^2 \equiv 1 \bmod p$ and $g^r \equiv 1 \bmod p$

Attack to Diffie-Hellman Key Exchange

➜ Traditional *Man-in-the-Middle attack*:
Eve pretends to Alice as Bob and to Bob as Alice



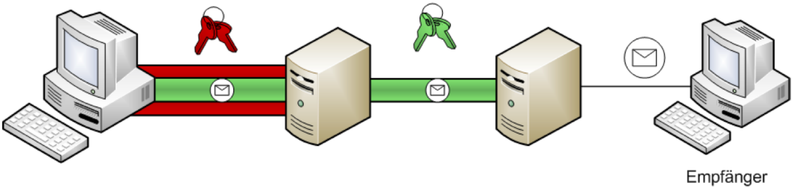
5 Alice calculates $K_a := (B_e)^a \bmod p$ und Bob $K_b := (A_e)^b \bmod p$

6 Eve calculates $K_a := (A_a)^z \bmod p$ und $K_b := (B_b)^z \bmod p$

➜ Using K_a und K_b Eve is able to listen in on the entire communication and even make changes

<u>Countermeasure:</u> Signing and encrypting using asymmetric algorithms!

How to establish a TOR connection?

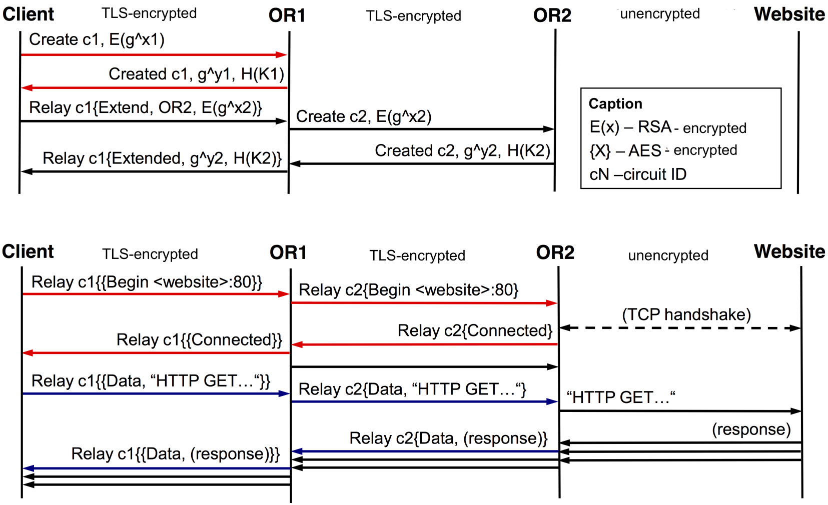


Procedure

1. Constructing Circuits (negotiating a symmetric key with each Onion Router on the circuit) based on asymmetric keys and Diffie-Hellman protcol
2. Data exchange via telescope-like channels based on TCP

Source: Figure of M. Ströbel, *Tor und Angriffe gegen TOR*, Seminar Paper, TUM, SS 2009

TOR Key Exchance & Communication



Source: S. Hasenauer, C. Kauba, S. Mayer: *Tor - The Second Generation Onion Router*, Seminar Slides, Uni Salzburg. http://www.cosy.sbg.ac.at/ held/teaching/wiss_arbeiten/slides_10-11/TOR.pdf, last access: 4.11.2014