Anonymous Authentication

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Chat Rooms

- A huge success for youth and a huge concern for parents
- 2006 survey (of 1500 US youth) by the Crimes against Children research centre
  - 13% of youth received unwanted sexual solicitations (down from 19% in 2001)
  - 4% of youth received aggressive solicitations in which solicitors attempted to make offline contact (up from 3% in 2001)
Chat Anonymity

- Why are online sexual solicitations a concern? Aren’t chats anonymous?
  - **Problem 1:** 34% of children interviewed posted personal information online where anyone could see it
  - **Problem 2:** even when personal information is not explicitly posted, it can be found through multiple sources (e.g., linked by the user’s pseudonym)
Solutions

• Education

• Parental control

• Law enforcement

• Technology
  – Set up “safe chat rooms” which deploy strong authentication methods
  – Allow children to access safe chat rooms only
  – This has its own problems…
Authenticated Chat Rooms

- One of the most attractive aspects of chat rooms is their anonymity
  - Children can be freed from the bonds of peer pressure and can speak freely
  - Children can ask advice about embarrassing situations, (seemingly) without fear of being traced

- The use of authentication destroys this aspect of chat rooms
Anonymous Authentication

- **Anonymous authentication – a contradiction in terms**
  - The user authenticates to the server and proves that she is an authorized user
  - The server has no idea which authorized user is authenticating

- **Is this really possible?**
  - Yes!

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Other Applications

• Professional forums
  – Technical papers, technical help, discussion forums
  – These are “great” sources of information for (legal) industrial espionage
  – If authentication is required (to allow only registered or paying users), the problem becomes far more acute

• Whistle blowing
  – We want to be sure that the report is really from an employee, but we want to protect them…

• Social networks
Another Issue – Revocable Anonymity

• Assume anonymous authentication is used

• Consider the case that one of the users is harassing others (or a pedophile stole someone’s authentication device and is using it)
  – The harasser’s account cannot be closed because we don’t know who the harasser is

• Revocable anonymity: when needed, and upon court order, can reveal identity
  – Without court order cannot reveal ID (provably)
Talk Outline

• Privacy
  – It is important – we all know that
  – But, *why* is it important?

• Anonymous web surfing
  – A very brief mention

• Anonymous authentication
  – Definitions
  – Protocols
  – Extensions
Privacy

• Everyone here agrees that privacy is important, but why?
  – Typically
    • The loss of privacy is an invasion into our personal space
    • Warren and Brandeis: privacy is “the right to be let alone”

• But what **concrete** damage is incurred?
Privacy – A Concrete Perspective

- We will consider concrete damage that may be incurred due to privacy loss
  - Understand these concrete damages are crucial for providing secure protocols that actually solve the problem at hand
Privacy and Self Censorship

• Storing user online information (emails, web and chat history and more), will likely result in self-censorship and inhibition
  – Highly likely if linked to real identity (and otherwise possible due to fear of later linkage)

• Think of the following uses of the Internet
  – Teenagers on chat sites
  – University forums where students comment on lecturers and courses
  – Web sites that provide information on sensitive medical issues, sexual health and practice, and psychological first aid
Privacy – A Naïve Perspective

• The above is usually only considered a problem if the user’s online identity is linked to her real-world identity

• Business Week/Harris Poll in 2000
  – 35% “not at all comfortable” with profiling online actions without linking to real identity
  – 81% “not at all comfortable” when this profiling is linked to real identity
    (My guess: 35% also concerned that link may happen)

• No identifier means no invasion of space
Information Without Identification

- If it is 100% guaranteed that a user’s profile can never be connected to their identity, then self censorship is unlikely to occur.

- Example – online newspaper
  - Newspaper records history of all articles read and all comments posted.
  - Information used to construct a newspaper tailored to your interests.
  - If identity never provided, this seems fine.
Basic Pseudonyms

- Based on this, a basic pseudonym that cannot be linked to the user’s real-world identity solves the problem!
- This is false!
  - And not only because it is impossible to guarantee that a link will never be made
Privacy Loss Without Identification

• Consider the newspaper example
  – A user’s profile reveals much about their political beliefs, financial status and so on
  – A newspaper with strong interests can tailor the content to influence the user
  – Since the newspaper has a lot of information about the user, and the user is not aware of this (or that it is getting tailored content), the user can be unfairly manipulated

• This infringes on the user’s personal autonomy
Pseudonyms?

- A pseudonym that cannot be linked to a user’s true identity does not solve the problem at all
  - In order to manipulate the user, the newspaper only needs to be able to link their history to their current actions
Industrial Espionage

- If a user’s real identity is not known, then the information gathered from a professional forum cannot be used to identify what company the user works for.
- However, it can be enough to just know that some competitor is researching and developing some product.
Price Discrimination

- Consider an online mall that tracks a buyer’s prior purchases and shopping habits
- If a seller knows that a buyer does not “shop around”, then they may charge higher prices
  - The seller has more information about what the buyer is willing to pay than what the buyer has about the price for which the seller is willing to sell
  - The buyer is not aware of this asymmetry
Conclusions

• Privacy is much more than being “let alone”

• Naïve solutions that rely on pseudonyms do not suffice

• We need *unlinkability* between transactions
  
  – This is not easy even when no registration or payment, and so no authentication, is required

  – This is very difficult if *authentication is required* (registering from scratch or paying again each time is unrealistic)
Anonymous Web Surfing

A Brief Survey
**Anonymous Routing**

- **Necessary infrastructure** for anonymous authentication
- **Two security goals**
  - **User anonymity**: modify packets so that user requests contain no identifying information
  - **Unlinkability**: ensure that an attacker who views Internet traffic (and possibly controls some routers) cannot know which client is interacting with which server
- **Achieving the goals**
  - **User anonymity**: not too difficult
  - **Unlinkability**: very difficult, depends on traffic
An Abstraction

• We assume that we have a magical mechanism that receives messages from all clients and sends them to their designated servers (without revealing the contents to an eavesdropper)
How is Anonymous Routing Achieved

• There are numerous methods
  – Mix-Nets
  – Onion routing
  – Dining cryptographers
  – Crowds

• See the paper for references
Anonymous Authentication

What it is, and how it can be achieved
The High-Level Idea

• It is impossible to authenticate a user without knowing something.

• Anonymous authentication protocols have the following properties:
  – The authenticating server *knows* that the user belongs to a given set of (authorized) users.
  – The authenticating server has *no idea* which member of the set has just authenticated.

• Of course, such a protocol must run on top of an anonymous routing mechanism.
Defining Security

• **Secure authentication**
  – No unauthorized user should be able to fool the server into granting it access (except with very small probability)
  – We mainly consider a public-key infrastructure model

• **Full (perfect) anonymity**
  – Let $\ell$ be the size of the set of users being considered
  – The protocol provides *perfect anonymity* if after authentication, the server can guess which user authenticated with probability at most $\frac{1}{\ell}$
Another Definition

• It is sometimes useful to consider a more relaxed definition (that suffices for most applications)

• Verifiable (perfect) anonymity
  – The user may receive a special *cheat* message as output
  – The guarantee is that if the user does not receive *cheat*, then the server can guess which user authenticated with probability at most $\frac{1}{\ell}$

• This suffices in many cases, because the user has not yet done anything
Solving the Mystery

• How is it possible to achieve anonymity?

• A naïve idea
  – Issue all users with the same password/secret key
  – This achieves perfect anonymity

• The problem
  – Cannot revoke a user’s account without changing everyone’s key!
Another Approach – Background

• Let $U_1, \ldots, U_n$ be the users and let user $U_i$ have a key-pair $(sk_i, pk_i)$ for some public-key encryption scheme (say, RSA)
  
  – The server has the record $(U_i, pk_i)$ for every user (realistically, this can use a PKI and certificates)
  
  – A user’s account can be cancelled by removing its record
  
  – We assume that each user knows all of the other users’ public keys
The Protocol – First Attempt

• **User** $U_i$ sends first message
  – Anonymous request to connect

• **Server first message**
  – The server chooses a long random string $w$
  – The server computes $c_i = E_{pk_i}(w)$ for every $i$
  – The server sends $c_1, \ldots, c_\ell$ to the user

• **User second message**
  – Upon receiving $c_1, \ldots, c_\ell$ the user $U_i$ computes $w = D_{sk_i}(c_i)$ and sends $w$ to the server

• **Server provides access if the user reply is** $w$
The Protocol – First Attempt

Server

Choose random \( w \)
\[
\forall j, c_j = E_{pk_j}(w)
\]

Accept \( w \)

User \( U_i \)

Request authentication
\[
c_1, \ldots, c_\ell
\]

\[
w = D_{sk_i}(c_i)
\]

\( w \)

\bullet Security...
Problem – Cheating Server

• A cheating server may encrypt a different $w_i$ for every user $U_i$
  – The user cannot tell the difference (it can only decrypt $c_i$)
  – The server can know exactly which user is authenticating by the value $w_i$ that it returns

• Solution
  – Have the server “prove” that it encrypted the same value under all public keys
Proof of Encryption Equality

• One possibility
  – The server sends all ciphertexts and proves that they encrypt the same value using a zero-knowledge proof
  – Very expensive!

• Note
  – The server cannot decrypt the ciphertexts for the user in order to check, because neither the user nor the server know the private keys
Proof of Encryption Equality

• Background:
  – All secure encryption is probabilistic

• RSA PKCS1#1 v1.5 encryption:
  – First pad as below, then compute \( x^e \mod N \)

  **RSA PKCS#1 v1.5 padding:**

  
  
  | 0002 | random | 00 | the message \( m \) |
A Proof of Encryption Equality

- The server needs to prove that all ciphertexts encrypt the same $w$

- The server cannot decrypt the ciphertexts, but can show how it encrypted them!
  - The server sends the random padding that it used to encrypt each ciphertext
  - The user can then re-encrypt under each key and check that all ciphertexts encrypt the same value
A Proof of Encryption Equality

• In more detail
  – Denote an encryption of $w$ with public-key $pk$ and random padding $r$ (as in PKCS#1) by $c = E_{pk}(w; r)$
  – Given a public-key $pk$, a ciphertext $c$, a plaintext $w$, and random padding $r$, check:
    • If $E_{pk}(w; r) = c$ then $c$ is an encryption of $w$
    – By unambiguity of decryption, $c$ is not an encryption of any value $\tilde{w} \neq w$
Proof of Encryption Equality

- Using the proof of equality
  - The server cannot send this proof before the user replies, because then the user knows $w$ and can get unauthorized access
  - If the server sends the proof after the user replies, then by sending a different $w_i$ to every $U_i$, it already knows the user’s identity

- Verifiable anonymity
  - The server sends it after, but if it learns the user’s identity, the user will know for sure that it cheated
The Full Protocol

Server

Choose random \( w \)

\[ \forall j, c_j = E_{pk_j}(w; r_j) \]

\( c_1, \ldots, c_\ell \)

Accept \( w \)

User \( U_i \)

Request authentication

\[ w = D_{sk_i}(c_i) \]

\[ w \]

\( r_1, \ldots, r_\ell \)

Verify:

\[ \forall j, c_j = E_{pk_j}(w; r_j) \]
Security Analysis

• Theorem
  – If the encryption scheme is secure against chosen-plaintext attacks, then the above is a secure authentication protocol that achieves verifiable anonymity

• Proof
  – **Secure authentication**: only an owner of one of the secret keys can find \( w \)
  – **Anonymity**: if server doesn’t cheat, all users return the same value \( w \)

• Formal proof (and definitions) in paper
Efficiency

- **Server overhead**
  - Compute one encryption per user (with RSA and small public exponent, not too expensive)

- **Client overhead**
  - Compute one encryption per user
  - Compute one decryption (on smartcard)

- **Important!**
  - Only one decryption on the smartcard
  - Any encryption scheme can be used and so standard smartcards and PKI can be utilized
Scalability

• What about very large sets of users?
  – Infeasible to carry out thousands of public-key operations to authenticate a single user

• k-anonymity: user is guaranteed to be hidden amongst k other users
  – We guarantee this, relative to random users
  – User chooses a random subset including itself and this is the set that is used
Implementation Issue

• The protocol assumes that all users know all of the public keys

• How is this accomplished?
  – If the server posts a set of public-keys (certificates), then how does the user know that they are real?
  – If 90% are fake, then a user choosing a subset of 100 random users, will actually only be hiding amongst about 10 real users
  – Conclusion: if the server is not trusted (even at this level), users must share public keys amongst each other
Achieving Full Anonymity

• What if full anonymity is desired?

• Background – ring signatures [RST]
  – A way of signing a message so that only someone from the “ring” could have signed, but it’s impossible to know who actually did
    • Unforgeability and anonymity
  – Rings can be formed by anyone, on their own
  – Initial application: “how to leak a secret”
  – Construction of [RST]: uses regular RSA, requires one decryption and an additional encryption for every user in the ring
Ring Signatures

$p_{k_1}$ $p_{k_2}$$p_{k_3}$ $p_{k_5}$ $p_{k_6}$ $s_{k_4}$
Anonymous Authentication with Ring Signatures

• Incorporate ring signatures into SSL
  – Use SSL with server and **client** authentication
  – In SSL, the client authentication is achieved by the client signing on the handshake messages
  – Use a **ring signature** instead of a normal one

• Security
  – **Secure authentication**: from unforgeability of ring signatures
  – **Anonymity**: from anonymity of ring signatures
Protocol Comparisons

- **Protocol based on encryption**
  - Seemingly higher bandwidth (but user needs to identify subset anyway)
  - Can use any secure encryption scheme (low requirements)

- **Protocol based on ring signatures**
  - Lower bandwidth (apart from identifying subset, requires same bandwidth as SSL with regular client authentication)
  - Assumes strong assumptions: *ideal cipher*
Revocable Anonymity

• In some cases, anonymity needs to be revoked
  – Ban access to users who misbehave
    • Hostile users in anonymous chat
    • Criminal activity

• When anonymous authentication is used, this cannot be done

• Revocable anonymity
  – There exists a court authority who can revoke anonymity when required (and only it can revoke)
Achieving Revocable Anonymity

• There exist solutions, but they are all expensive and require dedicated hardware
  – They don’t use “standard” encryption techniques

• As of yet, we also don’t have a solution that doesn’t require a special-purpose smartcard
  – We do have solutions that are simple extensions of our protocols
Achieving Revocable Anonymity

• A first attempt
  – The court authority has a public encryption-key $pk_C$
  – The user $U_i$ includes an encryption $E_{pk_C}(ID_i)$ in its authenticating message to the server

• Revocability
  – If needed – and under court order – the court authority decrypts the additional ciphertext and finds the user’s identity $ID_i$

• Problem
  – A cheating user can encrypt garbage or someone else’s ID
Solving the Problem

- We need to **bind** the encryption of the user’s identity with its authentication message
- We assume that the user is given a smartcard by the organization, and cannot modify it
  - The organization initializes the keys and so the user cannot replace it with a different smartcard
- **The requirement:**
  - If the user succeeds in authenticating, then its encrypted identity must be received by the server
  - We view the user as a man-in-the-middle adversary
Revocable Anonymity with Ring Signatures

- Additional SSL modification
  - The court authority has a public encryption-key $p_kC$.
  - The user $U_i$ includes an encryption $E_{p_kC}(ID_i)$ in the handshake messages.
  - The handshake messages are all signed by the smartcard.
  - Technically:
    - The smartcard receives a hash $z$ of the handshake messages.
    - The smartcard signs upon $z$ and the ciphertext $c$. 

Revocable Anonymity with Ring Signatures

• Security
  – The smartcard operations are atomic
  – If the user modifies the ciphertext (that encrypts its identity), the ring signature generated by the smartcard will fail
  – In this case, the user will fail to gain access
Revocable Anonymity Using Encryption

• It is also possible to achieve a similar effect using our original protocol
  – The full description appears in the paper
Password-Based Anonymous Authentication

• What if we don’t have a PKI setup?
  – We wish to use symmetric keys, or passwords (regular, one-time or whatever)

• We present a partial solution that can be based on any authentication mechanism (even biometrics)
High-Level Protocol

- **Step 1 – standard authentication**
  - The user authenticates using regular, non-anonymous authentication

- **Step 2 – register temporary public key**
  - After authenticating, the user generates a temporary key pair \((pk, sk)\) and sends \(pk\) to the server
  - The server registers \(pk\) as an authorized public-key

- **Step 3 – disconnect and re-authenticate**
  - The user disconnects and connects again, running an anonymous authentication protocol using \(pk\)
Properties of the Protocol

• **Security**
  – **Authentication:** no problems here
  – **Anonymity:** this is preserved as long as the server cannot link the anonymous authentication request to the user who just disconnected

• **Achieving anonymity**
  – User must either register key well before authenticating, or wait until a number of users join
  – Can use time slots
Properties of the Protocol

- User keys
  - This protocol intensifies the problem of how users know other users’ public keys
  - Need to use some trusted bulletin board (not run by the same organization and assuming no collusion)
Conclusions

• Privacy is far more than just the “right to be let alone”
  – Online entities can learn large amounts of information and use that information against us, giving them an asymmetric advantage
  – We need unlinkability to preserve our privacy

• Anonymous routing is the basic infrastructure needed for preserving privacy (unlinkability)

• The above is fine, as long as authentication is not needed
Conclusions

• If authentication is needed, anonymity can still be preserved
  – We saw two protocols
  – Implementation has a real cost, but a classic security/efficiency tradeoff makes it realistic (hide inside a not-too-large set of users)
  – Revocable anonymity is possible (but requires dedicated smartcards; not too bad with the invent of JavaCards, but still a disadvantage)
  – Partial solutions based on passwords are also possible
Future Work

• Revocation
  – Devise protocols that use only standard smartcard operations

• Passwords
  – Provide more satisfactory solutions that have stronger guarantees

• System
  – Come up with other methods of sharing public keys of users, so that server cannot introduce fake ones
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