Authentication Protocols

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"Network Security", C. Kaufman, R. Perlman, M. Speciner, Second Edition, Addison-Wesley, 2002.

Outline

- Overview of Authentication Systems
    - [Chapter 9]
- Authentication of People
    - [Chapter 10]
- Security Handshake Pitfalls
    - [Chapter 11]
- Strong Password Protocols
    - [Chapter 12]

Who Is Authenticated?

- Human:
  - Limited in terms of computation power and memory
- Machine:
  - More powerful: long secrets, complex computation
- Hybrid:
  - User is only authorized to execute some actions from a restricted set of machines
  - Users equipped with computation devices

Password-Based Authentication

- Node *A* has a secret (*password*): e.g., *"lisa"*
- To authenticate itself *A* states the password
- No cryptographic operation because:
  - Difficult to achieve by humans when connecting from dumb terminals (less true today with authentication tokens)
  - Crypto could be overly expensive in implementation time or processing resources
  - Export or legal issues
- Problems:
  - Eavesdropping, cloning, etc.
- Should not be used in networked applications

Offline vs. Online Password Guessing

- Online attack:
  - How? try passwords until accepted
  - Protection:
    - Limit number of trials and lock account: e.g., ATM machine
      - DoS problem: lock all accounts
    - Increase minimum time between trials
    - Prevent automated trials: from a keyboard, Turing tests
    - Long passwords: pass phrases, initials of sentences, reject easy passwords
    - What is the protection used by Yahoo? Hotmail? Gmail?

- Offline attack:
  - How?
    - Attacker captures $X = f(password)$
    - Dictionary attack: try to guess the password value offline
    - Obtaining X in a unix system: "ypcat passwd"
    - Unix system: using the *salt*

  - Protection:
    - If offline attacks are possible then the secret space should be large

L0pht Statistics (old)

- L0phtCrack against LM (LanMan – Microsoft)
  - On 400 MHz quad-Xeon machine
  - Alpha-numeric: 5.5 hours
  - Alpha-numeric some symbols: 45 hours
  - Alpha-numeric-all symbols: 480 hours
- LM is weak but was still used by MS for compatibility reasons up to Windows XP, ... NTLM, ...
- Side Note on choosing good passwords:

  http://www.atstake.com/products/lc/best_practices.html
  - Best practice from: SANS, MS, Red-Hat, etc.

Password Length

- Online attacks:
  - Can 4/6 digits be sufficient if a user is given only three trials?

- Offline attacks:
  - Need: 64 random bits = 20 digits
    - Too long to remember by a human!
  - Or 11 characters from a-z, A-Z, 0-9, and punctuation marks
    - Too long to remember by a human
  - Or 16 characters pronounceable password (a vowel every two characters)
  - Conclusion:

    A secret a person is willing to remember and type will not be as good as a 64-bit random number

Storing User Passwords

- Alternatives:
  - Each user's secret information is stored in every server
  - The users secrets are stored in an *authentication storage node*
    - Need to trust/authenticate/secure session with the ASN
  - Use an *authentication facilitator node.* Alice's information is forwarded to the authentication facilitator who does the actual authentication
    - Need to trust/authenticate/secure session with the AFN
- Authentication information database:
  - Encryption
  - Hashed as in UNIX (allows offline attacks)

Other Issues Related to Passwords

- Using a password in multiple places:
  - Cascade break-in vs. writing the list of passwords
- Requiring frequent changes
  - How do users go around this?
- A login Trojan horse to capture passwords
  - Prevent programs from being able to mimic the login: X11 (take the whole screen), read keyboard has “?”, “Ctrl-Alt-Del”
  - What happens after getting the password?
    - Exit => alarm the user, freeze, login the user

Initial Password Distribution

- Physical contact:
  - How: go to the system admin, show proof of identity, and set password
  - Drawback: inconvenient, security treats when giving the user access to the system admin session to set the password
- Choose a random strong initial password (pre-expired password) that can only be used for the first connection

Authentication Tokens

- Authentication through what you have:
  - Primitive forms: credit cards, physical key
  - Smartcards: embedded CPU (tamper proof)
    - PIN protected memory card:
      - Locks itself after few wrong trials
    - Cryptographic challenge/response cards
      - Crypto key inside the card and not revealed even if given the PIN
      - PIN authenticates the user (to the card), the reader authenticates the card
    - Cryptographic calculator
      - Similar to the previous card but has a display (or speaker)

Address-Based Authentication

- Trust network address information
- Access right is based on *users@address*
- Techniques:
  - Equivalent machines: smith@machine1 ≡ john@machine2
  - Mappings: <address, remote username, local username>
- Examples:
  - Unix: */etc/host.equiv*, and *.rhost* files
  - VMS: centrally managed proxy database for each <computer, account> => file permissions
- Threats:
  - Breaking into an account on one machine leads to breaking into other machines accounts
  - Network address impersonation can be easy in some cases. How?

Cryptographic Authentication Protocols

- Advantages:
  - Much more secure than previously mentioned authentication techniques
- Techniques:
  - Secret key cryptography, public key crypto, encryption, hashing, etc.

Other Types of Human Authentication

- Physical Access

- Biometrics:
  - Retinal scanner
  - Fingerprint readers
  - Face recognition
  - Iris scanner
  - Handprint readers
  - Voiceprints
  - Keystroke timing
  - Signature

Passwords as Crypto Keys

- Symmetric key systems:
  - Hash the password to derive a 56/64/128 bits key
- Public key systems:
  - Difficult to generate an RSA private key from a password
  - Jeff Schiller proposal:
    - Password => seed for random number generator
    - Optimized by requesting the user to remember two numbers
      - E.g. (857, 533): p prime number was found after 857 trials, and q after 533 trials
    - Known public key makes it sensitive to offline attacks
  - Usual solution:
    - Encrypt the private key with the users password and store the encrypted result (e.g., using a directory service)

Eavesdropping & Server Database Reading

- Example of basic authentication using public keys:
  - Bob challenges Alice to decrypt a message encrypted with its public key

- If public key crypto is not available protection against **both** eavesdropping and server database reading is difficult:
  - Hash => subject to eavesdropping
  - Challenge requires Bob to store Alice’s secret in a database

- One solution:
  - Lamport’s scheme allows a finite number of authentications

Key Distribution Center

- Solve the scalability problem of a set of n nodes using secret key
  - $n*(n-1)/2$ keys
- New nodes are configured with a key to the KDC
  - e.g., K_A for node A
- If node A wants to communicate with node B
  - A sends a request to the KDC
  - The KDC securely sends to A: $E_{KA}(R_{AB})$ and $E_{KB}(R_{AB}, A)$
- Advantage:
  - Single location for updates, single key to be remembered
- Drawbacks:
  - If the KDC is compromised!
  - Single point of failure/performance bottleneck => multiple KDC?

Multiple Trusted Intermediaries

- Problem:
  - Difficult to find a single entity that everybody trusts
- Solution: Divide the world into domains
  - Multiple KDC domains interconnected through shared keys

  - Multiple CA domains: certificates hierarchy

Certification Authorities

- How do you know the public key of a node?
- Typical solution:
  - Use a trusted node as a certification authority (CA)
  - The CA generates certificates: Signed(A, public-key, validity information)
  - Everybody needs to know the CA public key
  - Certificates can be stored in a directory service or exchanged during the authentication process
- Advantages:
  - The CA doesn't have to be online => more physical protection
  - Not a performance bottleneck, not a single point of failure
  - Certificates are not security sensitive: only threat is DoS
  - A compromised CA cannot decrypt conversation but can lead to impersonation
  - A certification hierarchy can be used: e.g., X.509

Certificate Revocation

- What if:
  - Employer left/fired
  - Private key is compromised
- Solution: similar to credit cards
  - Validity time interval
  - Use a Certificate Revocation List (CRL): X.509
    - For example: lists all revoked and unexpired certificates

Session Key Establishment

- Authentication is not everything
  - What could happen after authentication?
    - E.g., connection hijacking, message modification, replay, etc.
  - Solution use crypto => need a share key between communicating entities because public encryption/decryption is expensive
  - Practically authentication leads to the establishment of a shared key for the session
    - A new key for each session:
      - The more data an attacker has on a key the easier to break
      - Replay between sessions
      - Give a relatively “untrusted” software the session key but not the long-term key
      - Good authentication protocol can establish session keys that provide forward secrecy

Delegation

- Give a limited right to some third entity:
  - Example: printserver to access your files, batch process
- How?
  - Give your password?
  - ACL
  - Delegation

Security Handshake Pitfalls

- Developing a new encryption algorithm is believed to be an “art” and not a “science”
- Security protocols build on top of these algorithms and have to be developed into various types of systems

- Several Cryptographic Authentication Protocols exist however:
  - Several protocols were proven to have flaws
  - Minor modifications may lead to flaws
  - Use in a different context may uncover flaws or transform a non-serious flaw into a serious one

Login Only: Shared Secrets

- Sending the password on the clear is not safe: use shared secrets
  - Challenge response: *B* sends *R* and *A* has to reply $f(K_{AB}, R)$. Weaknesses:
    - Authentication is not mutual
    - If the subsequent communication is not protected: hijacking treat
    - Offline attack by an eavesdropper using *R* and $f(K_{AB}, R)$
    - An attacker who successfully reads *B*'s database can impersonate *A*
      - *Cascade effect if the same password is used on multiple servers*
  - Variants:
    - *B* sends: $K_{AB}\{R\}$, and *A* replies *R*
      - Requires reversible cryptography which may be limited by export legislation
      - Dictionary attacks if *R* is a recognizable value (padded 32 bits) don't need eavesdropping
    - *A* sends $K_{AB}\{timestamp\}$ (a single message)
      - Requires: clock synchronization
      - Problems with impersonation:
        - within the clock skew: remember timestamp
        - at another server: include *B* in message

Login Only: One-Way Public Key

- Shared secrets are vulnerable if *B*'s database is compromised
- Public key protocols:
  - *A* send the signature of *R* using its public key: $[R]_A$
  - Advantage:
    - *B*'s database is no longer security sensitive to unauthorized disclosure
  - Variant: *B* sends $\{R\}_{public\text{-}A}$, *A* has to recover *R* and send it back
  - Problem:
    - You can trick *A* into signing a message or decrypting a message
  - General solution: never use the same key for two purposes

Mutual Authentication: Shared Secret

- Basic protocol: 5 messages,
- Optimized into 3 rounds but becomes subject to the Reflection attack:
  - *C* impersonates *A* by initiating two sessions to *B* [both single/multiple servers]
- Solutions:
  - Use different keys for *A* -> *B* authentication and *B*->*A* authentication
    - For example: $K_{B\text{-}A} = K_{A\text{-}B} + 1$
  - Use different challenges:
    - For example: challenge from the initiator be an odd number, while challenge from the responder be an even number, concatenate the name of the challenge creator to the challenge
- Another problem: password guessing without eavesdropping
- Solution: 4 messages protocol where the initiator proves its identity first
- Alternative two messages protocol using *timestamp* and *timestamp*+1 for R_1 and R_2

Mutual Authentication: Public Keys

- Three messages protocol:
  - $A \text{ -> } B$: A, $\{R_2\}_B$
  - $B \text{ -> } A$: R_2, $\{R_1\}_A$
  - $A \text{ -> } B$: R_1
- Problems:
  - Knowing the public keys
- Solutions:
  - Store Bob’s public key encrypted with Alice’s password in some directory
  - Store a certificate of Bob’s public key signed by Alice’s private key

Integrity/Encryption for Data

- Key establishment during authentication

- Use $f(K_{A\text{-}B})\{R\}$ as the session key where R is made out of R_1 and R_2
  - Example: $f(K_{A\text{-}B}) = K_{A\text{-}B} + 1$
  - Why not use $K_{A\text{-}B}\{R+1\}$ instead of $f(K_{A\text{-}B})$?
- Rules for the session key:
  - Different for each session
  - Unguessable by an eavesdropper
  - Not $K_{A\text{-}B}\{X\}$

Two-Way Public Key Based Authentication + Key Setup

- First attempt:
  - *A* sends a random number encrypted with the public key of *B*
  - Flaw: *T* can hijack the connection using her own *R*
- Second attempt:
  - *A* sends $[\{R\}_B]_A$: encrypt using public key of *B* and then private key of *A*
  - If someone records the conversation and then gets access to *B* key it can recover *R*
- Third attempt:
  - Both *A* and *B* participate through R_1 and R_2 shares: session key $R_1 \oplus R_2$
- Fourth alternative:
  - Use Diffie-Hellman key establishment protocol and each entity signs its contribution

One-Way Public Key Based Authentication

- Context:
  - Only one of the parties has a public key (e.g., SSL server)
  - First the server is authenticated
  - If needed the user is authenticated (e.g., using a password)
- First solution:
  - *A* sends a random number encrypted with *B*'s public key
  - The random number is used as a session key
  - Problem: if an attacker records the communication and later on breaks into *A* it can decode the whole communication
- Second solution:
  - Use Diffie-Hellman with *B* signing his contribution

Privacy and Integrity

- Privacy:
  - Use a secret key algorithm to encrypt the data
- Integrity:
  - Generate a Message Authentication Code (MAC)
- No clean solution for merged privacy and integrity:
  - Use two keys (may be one derived from the other)
  - Use a weak checksum then encrypt
  - Use two different algorithms for encryption/integrity (e.g., AES) and MAC (e.g., HMAC/SHA1)
- Replays:
  - Use sequence number to avoid replays, or
  - Include info about previous message
- Reflection: replay the message in a different direction
  - Different range for each direction
  - Use a direction bit
  - Use a direction dependent integrity algorithm
- Key rollover: change keys periodically during the communication

Needham-Schroeder Authentication 1978

- Basis for Kerberos and many other authentication protocols
- Uses *NONCE* (Number ONCE):
  1. $A \rightarrow KDC$: N_1, A, B
  2. $KDC \rightarrow A$: $K_A\{N_1, B, K_{AB}, \textit{ticket-to-B}\}$; $\textit{ticket-to-B} = K_B\{K_{AB}, A\}$
  3. $A \rightarrow B$: $\textit{ticket-to-B}, K_{AB}\{N_2\}$
  4. $B \rightarrow A$: $K_{AB}\{N_2\text{-}1, N_3\}$
  5. $A \rightarrow B$: $K_{AB}\{N_3\text{-}1\}$
  - Why N_1? *T* has stolen the old key of *B* and previous request from *A* to KDC requesting to communicate with *B*
  - Why *B* in second message?
  - Reflection attack?

Expanded Needham-Schroeder

- Vulnerability of basic protocol:
  - *T* steals *A*'s key and can impersonate *A* even after *A* changes it's key (ticket stays valid)
- Proposed solution [Need87]
  - Before talking to the *KDC* *B* gives *A* a nonce that has to be included in the ticket => 7 messages protocol

Otway-Rees Authentication 1987

1. $A \rightarrow B$: N_C, A, B, $K_A\{N_A, N_C, A, B\}$
2. $B \rightarrow KDC$: $K_A\{N_A, N_C, A, B\}$, $K_B\{N_B, N_C, A, B\}$
3. $KDC \rightarrow B$: N_C, $K_A\{N_A, K_{AB}\}$, $K_B\{N_B, K_{AB}\}$
4. $B \rightarrow A$: $K_A\{N_A, K_{AB}\}$
5. $A \rightarrow B$: $K_{AB}\{$ *anything recognizable* $\}$

NONCES

- Potential properties:
  - Non-repeated, unpredictable, time dependent
  - Context dependent
- A nonce may have to be unpredictable for some challenge response protocols (with no session key establishment)
  - Sequence number doesn’t work for challenge response: $K_{AB}\{R\}$
- One solution is to use cryptographic random number generators

Random Numbers

- If the random number generation process is weak the whole security system can be broken
- Pure randomness is very difficult to define
- Usually we differentiate:
  - *Random*: specialized hardware (e.g., radioactive particle counter)
  - *Pseudorandom:* a deterministic process determined by its initial state
    - For testing purpose: hashing a seed using a good hashing function can work
    - For security purpose: long seed, good hashing function (FIPS186)

Performance Considerations

- Metrics:
  - Number of cryptographic operations using a private key
  - Number of cryptographic operations using a public key
  - Number of bytes encrypted/decrypted using a secret key
  - Number of bytes to be cryptographically hashed
  - Number of messages transmitted
- Notes:
  - Private key operations are usually much more expensive than public key operations
- Some optimization techniques:
  - Caching information such as tickets

Authentication Protocols Checklist

- Eavesdrop:
  - Learn the content, learn info to impersonate *A*/*B* later or to another replica, offline password guessing
- Initiating a conversation pretending to be *A*:
  - Impersonate *A*, offline password guessing, delayed impersonation, trick *B* to sign/decrypt messages
- Lie in wait at *B*'s network address and accept connections from *A*:
  - Immediate/delayed impersonation of *B* or *A*, offline password guessing, trick *A* to sign/decrypt messages
- Read *A*/*B*'s database:
- Sit actively/passively on the net between A and B (router):
  - Offline password guessing, learn the content of messages, hijack connections, modify/rearrange/replay/reverse direction of message
- Combinations:
  - Even after reading both *A* and *B* databases *T* shouldn't be able to decrypt recorded conversations
  - Even after reading *B*'s database and eavesdropping on an authentication exchange it shouldn't be possible to impersonate *A* to *B*

STRONG PASSWORD PROTOCOLS

Context & Solutions

- Context:
    - *A* wants to use any workstation to log into a server *B*
    - *A* has only a password
    - The workstation doesn’t have any user-specific information (e.g., users’s trusted CAs, or private keys)
    - The software on the workstation is trustworthy
- Potential solutions:
    - Transmit the password in the clear
    - Use Diffie-Hellman key establishment (vulnerable to *B* impersonation)
    - Use SSL (relies on trust anchors: trusts configuration and certificates)
    - Challenge response authentication using a hash of the password as a key (vulnerable to dictionary attacks)
    - Use Lamport’s hash or S/KEY
    - Use a strong password protocol (secure even if the shared secret could be broken by an offline dictionary attack

Lamport's Hash: One Time Password

- Allows authentication
  - Resistant to eavesdropping and reading Bob's database
  - Doesn't use public key cryptography
- *B*'s database:
  - Username (e.g., *A*),
  - *n* (integer decremented at each authentication)
  - $hash^n(password)$
- Initialization:
  - Set *n* to a reasonably large number (e.g., 1000)
  - The user registration software computes: $x_n = hash^n(password)$ and sends x_n and *n* to *B*

Lamport's Hash (Cont'd)

- Authentication:
  - *A* connects to a workstation and gives her username and password
  - The workstation sends *A's* username to *B*
  - *B* sends back *n*
  - The workstation computes $hash^{n-1}(password)$ and sends it to *B*
  - *B* computes the hash of the received value and compares it with the stored value of $hash^{n}(password)$
  - If equal: decrement *n* and store the last received value
  - When *n* gets to 1, *A* needs to reset its password (in a secure way)
- Enhancement: *Salt*
  - $x_1 = hash(password \mid salt)$
  - Advantage:
    - Use the same password on multiple servers
    - Makes dictionary attacks harder (similar to Unix)
    - Do not have to change the password when *n* reaches 1 (just change the salt)

Pros and Cons

- Advantages:
  - Not sensitive to eavesdropping, or reading *B*'s database
- Disadvantages:
  - Limited number of logins
  - No mutual authentication, difficulty to establish a common key, or prevent man-in-the-middle
    - One can use this scheme followed by a Diffie-Hellman key establishment: but this is vulnerable to connection hijacking
  - Small *n* attack:
    - *T* impersonates *B*'s address and sends back a small value of *n* (e.g., 50)
    - If the real value of *n* at *B* is 100 => *T* can impersonate *A* 50 times
- Use in the "human and paper" environment:
  - Print the list and give it to *A* (the user won't go back on the list)
  - Use 64 bits out of 128 MD5 hash function
  - Resiliency to small *n* attack
  - What if you lose the list!
- Deployed in S/Key (Phil Karn) RFC 1938

Strong Password Protocols

- Goal:
  - Prevent off-line attacks
  - Even if eavesdropping or impersonating addresses
- Basic Form: Encrypted Key Exchange (EKE) [Bellovin & Merritt]
  - A and B share a weak secret W (derived from A's password)
  - A and B encrypt their DH contributions using W
  - Why is it secure? because $W\{g^a \bmod p\}$ is just a random number and for any password W their could exist a $r = g^a$ such that $W\{r\}$
- Variants:
  - Simple Password Exponential Key Exchange (SPEKE): use $g = W$
  - Password Derived Moduli (PDM): Use $p = f(W)$

Subtle Details

- A simple implementation may lead to flaws
- EKE:
  - If p is a little more that a power of 2
  - g^a has to be less than p
  - The attacker can try a password and if $GUESS\{W\{g^a \bmod p\}\}$ is higher that p then discard *guess*
  - A password from a space of 50’000 can be guessed after about 20 exchanges
  - Solution?
- SPEKE:
  - Small problem if W is not a perfect square mod p

Augmented Strong Password Protocol

- Goal:
  - If an attacker steals *B*'s database but doesn't succeed with an offline attack he cannot impersonate *A*
- How:
  - avoid storing *W* in *B*'s database but only something derived from *W*
- Augmented PDM:
  - *B* stores "*A*", p, $2^W \bmod p$
  - *A* sends $2^a \bmod p$
  - *B* sends: $2^b \bmod p$, $hash(2^{ab} \bmod p, 2^{bW} \bmod p)$
  - *A* sends $hash'(2^{ab} \bmod p, 2^{bW} \bmod p)$

Augmented Strong Password Protocol

- RSA variant:
  - B stores: "A", W, A's public key, $Y = W'\{A$'s private key$\}$
  - A sends: A, $W\{g^a \bmod p\}$
  - B sends: $W\{g^b \bmod p\}$, $(g^{ab} \bmod p)\{Y\}$, c
  - A replies: $[hash(g^{ab} \bmod p, c)]_{sign\text{-}A}$

Secure Remote Protocol (SRP)

- Invented by Tom Wu 1998, RFC2945
  - B stores g^W mod p
  - A choose a and sends: "A", g^a mod p
  - B choose b, c_1, 32-bit number u, and sends $g^b + g^W$ mod p, u, c_1
  - => Share key is: $K = g^{b(a+uW)}$ mod p
  - A sends: $K\{c_1\}$, c_2
  - B sends: $K\{c_2\}$

  - How is the common key computed on both ends?

Credentials Download Protocols

- Goal:
  - A can only remember a short password
  - When using a workstation A needs its environment (user specific information)
  - The user specific information could be downloaded from a directory if A knew its private key
  - Strong Password protocols can help
- Protocol based on EKE:
  - B stores: "A", W, $Y = W'$\{A's public key\}
  - A sends: "A", $W\{g^a \bmod p\}$
  - B sends: $g^b \bmod p$, $(g^{ab} \bmod p)\{Y\}$