

CS314s1 - lectures 12-23

Low level protocols, routing

Dr Brian Carpenter

- 12, 13 – Security mechanisms
 - 14 -16 – Link control, flow control
 - 17 -19 – Ethernet, wireless
 - 20, 21 – Bridges, switches, VLANs
 - 22, 23 – Routing
- Dates: 3, 7, 10, 21, 28 April, 1, 5, 8 May.
 - *Term test on 24 April*
 - Approximately covers Shay 7.1-7.5, 8, 9 (not 9.6), 10
 - Assignments 2 and 3
 - **Questions:** brian@cs.auckland.ac.nz or room 303s.587
(most days between 10 a.m. and 4 p.m.)

About the level of detail

- I sometimes give more technical details than the text books, because I want all students to feel that they can see how the various protocols could be coded in a programming language.
- The level of detail given in Shay should be sufficient for the exam questions.

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Lectures 12, 13:

Security mechanisms

- Introduction (Shay 7.1)
- Encryption (Shay 7.2-7.4)
- Authentication (Shay 7.4-7.5)

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Security 101

Properties of secure data: **CIA**

- **C**onfidentiality: no unauthorised user can read
- **I**ntegrity: no unauthorised user can write
- **A**vailability: all authorised users can read and write

Confidentiality - provided by *encryption*

Integrity - provided by *authentication* and *cryptographic signature*

Availability - means preventing *denial of service attacks*

For now we'll consider techniques for encryption and authentication.

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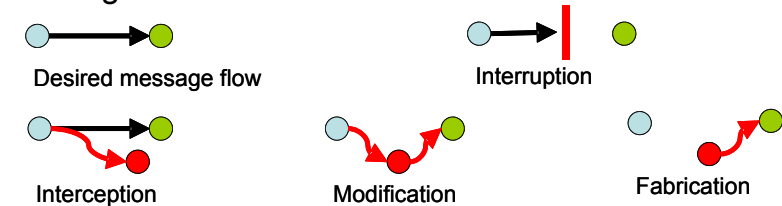
Security functions

- The **Gold Standard**, and some **additional functions**:
 - **Authentication**: are you who you say you are?
 - All claims to identity can be verified.
 - **Authorisation**: who is permitted to do which operations to what?
 - Users can't increase their own authority.
 - **Auditing**: what has happened on this system?
 - System administrators can investigate problems.
 - **Identification**: what human (or object) is this?
 - Different from authentication (a proof of an identity) or authorisation (a decision to allow an activity).
 - **Non-repudiation**: can you prove this event really did happen?
- To learn more: Lampson, "Computer Security in the Real World", *IEEE Computer* 37:6, June 2004.

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Types of attack

- *Modification* or *man in the middle*: an attacker changes a message;
- *Interruption* or *denial of service*: an attacker prevents delivery, often by floods of rubbish packets;
- *Fabrication* or *spoofing*: an attacker injects a message;
- *Interception* or *eavesdropping*: an attacker reads a message.



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Encryption is more than coding

- Coding schemes are designed to be decoded by an algorithm.
- Encryption schemes also need special knowledge to decode them.
- `Uijt jt b wfsz tjnqmf fods zqujpo`

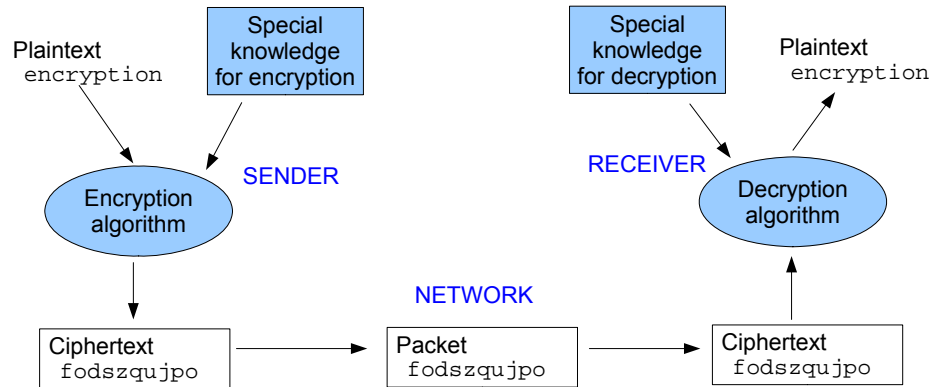
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Encryption is more than coding

- Coding schemes are designed to be decoded by an algorithm.
- Encryption schemes also need special knowledge to decode them.
- `Uijt jt b wfsz tjnqmf fods zqujpo`
- `This is a very simple encryption`
- The algorithm is "go back N letters"
- The special knowledge is "N=1"

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Encryption and decryption



Without the special knowledge, an intruder on the network cannot understand the packet, and cannot change it or insert a new one without being detected.

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Terminology

- Call the plaintext (the message) P
- The encryption algorithm is E
 - Its special knowledge is a key k
 - The ciphertext $C = E_k(P)$
- The decryption algorithm is D
 - Its special knowledge is a key k'
 - The plaintext $P = D_{k'}(C)$
 - By definition, $P = D_{k'}(E_k(P))$

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The Caesar code

- Probably the oldest cryptographic algorithm
- E is: go forward N letters in the alphabet, rotating from Z to A.
 - k is N
- D is: go back N letters in the alphabet, rotating from A to Z.
 - k' is N
- When $k = k'$ we speak of a *symmetric-key* algorithm or a *shared key*. Both ends must know the same secret key.

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What makes a good cryptographic algorithm?

- Assuming it's widely used, there's no point in trying to keep the algorithms E and D secret.
 - But you must keep your key secret
- It must be very hard (i.e. need thousands or more years of computing), even with complete knowledge of the algorithm, to try out all possible keys.
- Is the Caesar code a good algorithm?

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How big should the key be?

- Obviously this depends on the exact E and D algorithms, but considering that the attacker might be using a room full of supercomputers, let's assume (s)he can check one million keys per second.
- That's 31,536,000,000,000 keys per year.
- To be reasonably safe for 1000 years, you certainly need a pool of 31,536,000,000,000,000 keys to choose from.
- That's almost 2^{55}
- Modern cryptography goes further than that, as we'll see.

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Example: original DES (1977)

- Divide message into 64 bit blocks of plaintext
- Encrypt each block with a 56 bit key
 - The encryption process includes 18 major steps, including transposition of bit strings and XOR between parts of the message and parts of the key
 - The output is a 64 bit block of ciphertext

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Why DES uses XOR

- Note that XOR is in itself a simple symmetric cryptographic algorithm

$P=110011, k=010101 \rightarrow C=XOR(110011,010101)=100110$

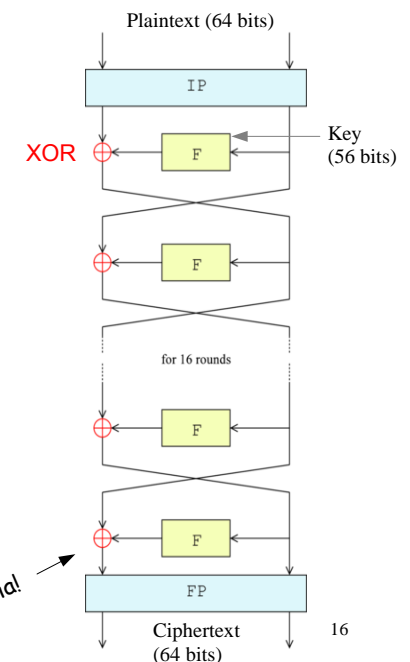
$C=100110, k=010101 \rightarrow P=XOR(100110,010101)=110011$

- What DES does is build on this property using multiple cycles and transpositions to make the result more pseudo-random
- Hard to crack without knowing the 56 bit key.
 - Is 56 bits enough?

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Overview of DES

- IP = Initial Permutation (transposition)
- F = "Feistel" function (see Shay p. 289 for more details)
- FP = Final Permutation (swap and transposition, reverse of IP)
- In July 1998, the EFF's DES cracker (Deep Crack) broke a DES key in 56 hours. Cost: \$250,000.



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One step harder - DES-CBC

- CBC = Cipher Block Chaining
- Before each 64 bit plaintext block P_n is encrypted, XOR it with the previous cyphertext block C_{n-1} to add extra variability.
- After DES was broken, the first countermeasure was to use DES-CBC.
- Then...

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Triple DES

- Basically, apply DES three times running, so that $C = E_{k3}(D_{k2}(E_{k1}(P)))$
- where E is DES encryption and D is DES decryption
 - if $k1=k2=k3$ this is single DES for backwards compatibility
- Triple DES is still regarded as reasonably safe, but is slow, especially in software-only implementations.

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Advanced Encryption Standard (AES)

- Preferred to Triple DES due to longer keys and greater complexity
 - Also has better software performance
- 128 bit block cipher with 128, 192 or 256 bit keys
- Mathematically complex
 - like DES, involves transposition steps and XOR, but also includes substitution tables in each round
 - currently regarded as safe for all practical purposes

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The problem with symmetric keys

- Both ends must know the same key
- Doubles the risk of leaks
- Need to send the key initially from A to B, and how do you send the key in complete safety?
- If I need secure links to 100,000 customers I have to manage 100,000 keys

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Asymmetric keys

- Suppose I could decrypt using k' and tell all my customers to encrypt using k .
- If I keep k' secret, nobody else can decrypt messages that were encrypted using k .
- So if I receive a message encrypted with k saying "Today's AES key is 11011....011101" , only I can decrypt it, and the AES key is safe.
- In this case k is my public key (everybody knows it) and k' is my private key (nobody else knows it).

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RSA* algorithm

- Choose two large prime numbers p and q and multiply them together: $n = pq$
- Find k which has no common factors with $n' = (p-1) \times (q-1)$. k will be the encryption (public) key.
- Find k' such that $(kk'-1)$ is an exact multiple of n' . k' will be the decryption (private) key.
- Encryption consists of raising each block of the plaintext to the power k , modulo n .
- Decryption consists of raising each block of the cyphertext to the power k' , modulo n .

* Rivest, Shamir and Adleman

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Magic?

- RSA is based on number theory and seems like magic, but it works. Go through the example in Shay, or look at the excellent Wikipedia entry.

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Two ways to use RSA keys

1. Alice uses Bob's public key to encrypt a message to Bob; only Bob can decrypt it.
 - But anybody could pretend to be Alice!
2. Alice uses her private key to encrypt a hash of her message; Bob uses Alice's public key to decrypt and check the hash value.
 - Only Alice can perform this encryption, so the encrypted hash is a digital signature.
 - If the hash matches, Bob knows that Alice sent the message and nobody changed it.
 - More magic: in fact, Alice uses RSA decryption to "encrypt" the hash, and vice versa.

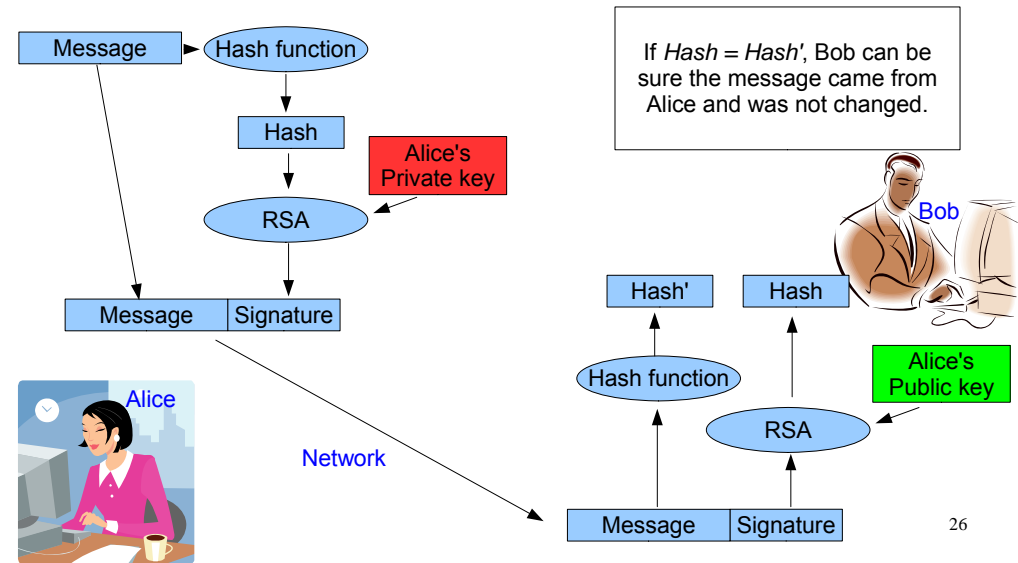
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Cryptographic Hash Functions

- A hash is a function somewhat like a checksum or CRC, but designed for cryptographic use.
 - Input is any length of message, and output is a fixed length hash value (at least 128 bits).
- Its mathematical design is not aimed at bit error detection, like a normal CRC, but at resistance to attack or detection of forgery.
 - In particular it should be very hard to find a fraudulent message that has the same hash as the genuine message
 - Preferred hash functions today are called SHA-224, SHA-256, SHA-384, SHA-512

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Signing a message: overview



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Who are Alice and Bob anyway?

- In many analyses of security algorithms, Alice and Bob are the two parties trying to communicate securely, and often Eve is the person trying to listen in or interfere
 - Apologies to anyone called Alice, Bob or Eve...



Alice



Eve



Bob

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What problems do Alice and Bob face?

- At the start, they can trust nothing - any message could be forged or read by Eve. They have to assume that:
 - Eve can see all their packets.
 - Eve can store packets and play them back later.
 - Eve can send her own packets with forged IP addresses.
 - Eve has a lot of computing power.

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The importance of authentication

- We could spend the whole semester on security, but will focus on authentication.
- Authentication that a message was sent by a given source and not tampered with is the key to preventing most types of attack:
 - detects modification and spoofing of messages
 - prevents repudiation of genuine messages
 - helps detection of floods of invalid messages
 - helps to secure the sending of encryption keys across an initially insecure channel

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How to authenticate that Bob is Bob

- We have to assume that Eve is trying to pretend to be Bob.
- So a message saying "I'm Bob" is suspect.
- A message signed with Bob's private key, that Alice can check with Bob's public key, is OK.
- But a message saying "Hi, I'm Bob and here's my public key", signed with the corresponding private key, isn't OK. Why not?

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Who do you trust?

- If *www.BobsWebSite.org* lists Bob's public key, are you willing to believe it?
- If yes:
 - How do you know that Eve didn't create that web site?
 - How do you know that Eve didn't hack that web site, even if it's one that Bob created?
 - Are you sure you aren't looking at *www.BobsWebSite.org*?
- Really, you can only trust a public key from a highly reputable source.

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What can Alice do with a reputable public key for Bob?

- Check that it really is Bob who's sending messages to her and that they are unchanged (since Eve cannot forge Bob's RSA signature).
- Prove later that he really did send them (since Alice cannot forge Bob's RSA signature).
- Send a secure message to Bob providing a symmetric key for AES encryption (since Eve cannot read a message encrypted with Bob's public key).
- Efficiently discard any flood of bogus messages from Eve (since she cannot forge anybody else's RSA signature)

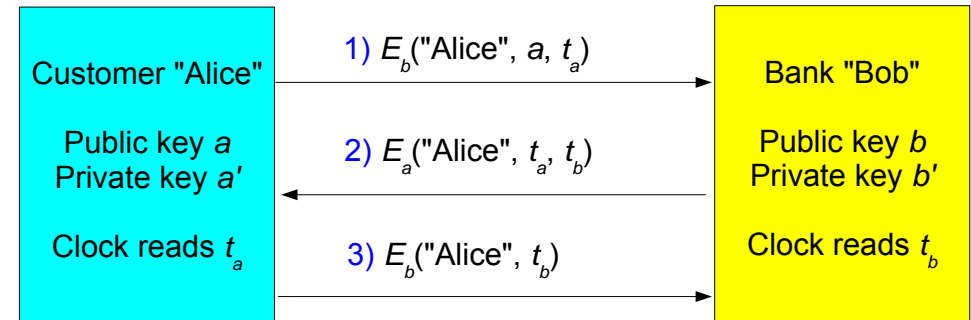
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A simple authentication protocol

- *Problem:* Convince a bank called Bob that you really are a customer called Alice.
- *Notation:*
 - E is RSA encryption
 - D is RSA decryption
 - a, a' are Alice's public and private keys
 - b, b' are Bob's public and private keys
 - thus $E_a(P)$ is plaintext P encrypted with Alice's public key, etc.
 - t_a, t_b are clock times on Alice's and Bob's clocks

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Does this work?



- 1) Alice provides her key and timestamp
- 2) Bob confirms timestamp and adds his own
- 3) Alice confirms Bob's timestamp

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What did Bob and Alice learn?

- Bob knows that "Alice" knew his public key
- Bob knows a public key for "Alice"
- Bob knows that "Alice" received his timestamp
- Alice knows that Bob knows her public key
- Alice knows that Bob received her timestamp
- Eve couldn't decipher the messages, but could store them
- *Has Alice proved her identity to Bob's server? (Authentication)*
- *Is Alice allowed to use Bob's service? (Authorization)*
- *Can Eve use a copy of message 3 to gain service? (Eavesdrop, then Replay; or Intercept, then Inject)*
- *What is the value of the timestamps?*

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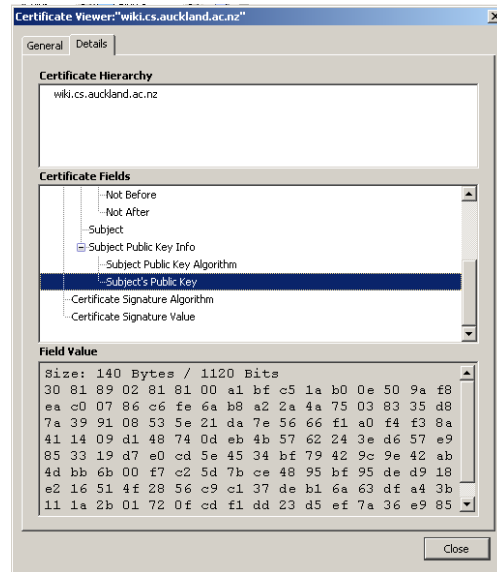
Authentication pitfalls

- How does Alice know she's talking to the genuine Bob?
 - This needs a source of trust for Bob's public key, typically an X.509 certificate
- How does Alice convince Bob she's the genuine Alice?
 - Typically this needs a reliable shared secret. The simplest kind is a pre-arranged password sent over an encrypted channel (e.g. encrypted with Bob's public key).

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X.509 certificate

- This is a document that is cryptographically signed by a trusted third party known as a CA (Certification Authority).
- Apart from the signature and administrative material, it contains the public key.
- ("X.509" identifies a particular international standard.)



Trust is recursive

- Instead of trusting Bob's web site, Alice now has to trust Bob's CA.
- Web browsers have the public keys for reputable CAs built into them.
- Now Alice has to trust the web browser.
- So she has to trust the download site where the web browser came from.
- Which means trusting the download site's CA.
- Trust is not easy...

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Summary on encryption and authentication

- We've seen how symmetric and asymmetric encryption systems work.
- They can be used to create secure channels and to check message authenticity.
- They can be used to build authentication protocols, but only based on some prior knowledge (a public key) and on some trusted third party.
- We'll see specific examples (TLS and SSH) later.

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