


Chapter 9

Lecture 9 - More encryption


Warp factor 9...

Tut 7, Q1: Hamming

Question: Calculate extra bits needed for encoding a 64 bit value, with two-bit error *detection*.

Answer: *Want a hamming distance of* 3*, so*

$$\begin{aligned}(n+1)2^m &\leq 2^n \\ 64+1 &\leq 2^r - r \\ R &= 7\end{aligned}$$

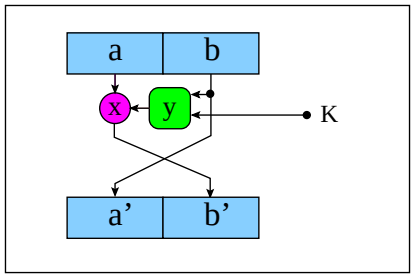
Tut 7, Q2: Diffie-Hellman

Question: Give a worked example of Diffie-Hellman

Answer: *Choose* $p = 1637$*, and* $g = 331$*. Alice chooses a secret key* $a = 1433$*, and Ted chooses* $b = 977$*.*

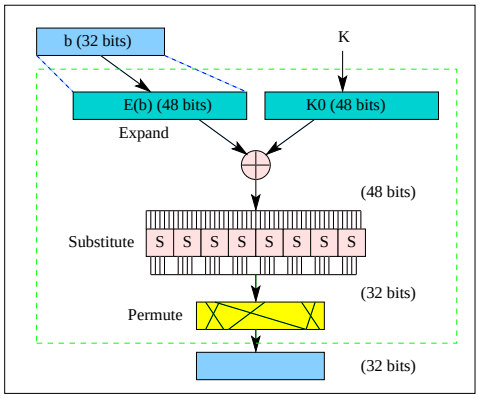
- ***(a)*** *Alice sends* $m_a = g^a \bmod p = 893$*.*
- ***(b)*** *Ted sends* $m_b = g^b \bmod p = 749$*.*
- ***(c)*** *Alice calculates* $m_b^a \bmod p = 441$*.*
- ***(d)*** *Ted calculates* $m_a^b \bmod p = 441$*. Have a shared key.*
- ***(d)*** *Bob has the difficult problem to calculate* $g^{ab} \bmod p$*.*

Tut 7, Q3: DES



- Same sort of confusion and diffusion algorithm. One round of 16, *performed for each 64 bits of the input.*
- $\langle a, b \rangle$ *are 32-bit registers. The* x *operations are XOR. Note* b' *is one-way...* K *is part of the key*

Tut 7, Q3: Feistel F function



56-bit key K is split into 16 subkeys - each 48 bits. S-Box and P-Boxes.

Tut7 Q4: Mono-alphabetic cipher

```
RECURSIVEPROGRAMSMAYREQUIRELARGENUMBERSOFPROCEDURECALLSANDST
ACKOPERATIONSANDMANYSUCHRECURSIVEPROGRAMSEXHIBITEXPONENTIALT
IMECOMPLEXITYDUETOTHETIMESPENTRECALCULATINGALREADYCOMPUTEDSU
BPROBLEMSASARESULTMETHODSWHICHTRANSFORMAGIVENRECURSIVEPROGRA
MTOANITERATIVEONEHAVEBEENINTENSIVELYSTUDIEDWEPROPOSEHEREANEW
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YSOLVINGRECURRENCESDERIVEDFROMTHEPROGRAMSOURCESOURPROTOTYPES
YSTEMAPTSR1ISANINITIALIMPLEMENTATIONOFTHEFRAMEWORKAUTOMATICA
LLYFINDINGSIMPLERCLOSEDFORMVERSIONSOFACLASSOFRECURSIVEPROGRA
MSTHOUGHINGENERALTHESOLUTIONOFRECURRENCESISEASIERIFTHEFUNCTI
ONSHAVEONLYASINGLEPARAMETERWESHOWAPRACTICALTECHNIQUEFORSOLVI
NGTHOSEWITHMULTIPLEPARAMETER
```

https://www-appn.comp.nus.edu.sg/~cs3235/mono.cgi

Tut7 Q5: Poly-alphabetic cipher

Answer: *Running the ic.perl script using shifts of 1,2,3 yields:*

```
Offset k = 1: 660 characters, 26 match Estimated IC: 0.0393
Offset k = 2: 659 characters, 21 match Estimated IC: 0.0318
Offset k = 3: 658 characters, 23 match Estimated IC: 0.0349
Offset k = 4: 657 characters, 42 match Estimated IC: 0.0639
Offset k = 5: 656 characters, 32 match Estimated IC: 0.0487
```

Note the sudden jump when the offset is 4, 8, 12 etc. This is fairly good evidence of a Vigenere cipher with a key length of 4. Note also the values... $\frac{1}{26} = 0.0385$.

Tut7 Q5: Poly-alphabetic cipher

```
BOBBYHURRIEDDOWNTHEROADINTHEDIRECTIONOFTHECEDARSALWAYSHETRIE
DDESPERATELYTORECALLWHATHADOCCURREDDURINGTHOSEBLACKHOURSLAST
NIGHTANDTHISMORNINGBEFOREHEHADAWAKENEDINTHEEMPTYHOUSENEARHIS
GRANDFATHERSHOMEALLTHATREMAINEDWEREHISSENSATIONOFTRAVELINASW
IFTVEHICLEHISIMPRESSIONOFSTANDINGINTHEFORESTNEARTHECEDARSHIS
GLIMPSEOFTHEMASKEDFIGUREWHICHHEHADCALLEDHISCONSCIENCETHEECHO
INHISBRAINOFADREAMLIKEVOICESAYINGTAKEOFFYOURSHOESANDCARRYTHE
MINYOURHANDALWAYSDOTHATITSTHEONLYSAFEWAYTHESEFACTSTHENALONEW
ERECLEARTOHIMHEHADWANDEREDUNCONSCIOUSINTHENEIGHBOURHOODHISGR
ANDFATHERHADBEENSTRANGELYMURDEREDTHEDETECTIVEWHOHADMETHIMINT
HEVILLAGEPRACTICALLYACCUSEDHIMOFTHEMURDERANDHECOULDNTREMEMBE
```


Final lectures...

1. Thursday Oct 20 - Protocols
2. Thursday Oct 27 - Unix and NT
3. Thursday Nov 3 - Hari Raya and Hugh away - make up necessary
4. Thursday Nov 10 - final

What is the best solution to the missed lecture?

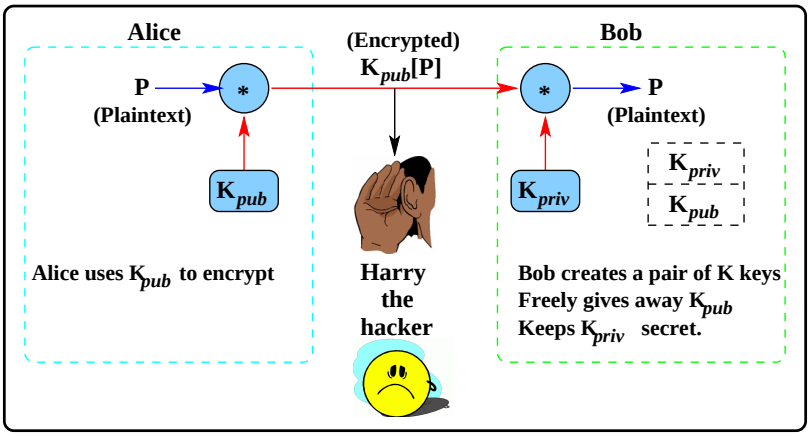
Uses of asymmetric encryption

1. Generating encrypted passwords with 1-way functions
2. Checking integrity by appending digital signature
3. Checking the authenticity of a message.
4. Encrypting timestamps with messages to prevent replay attacks.
5. Exchanging a key.

Asymmetric encryption

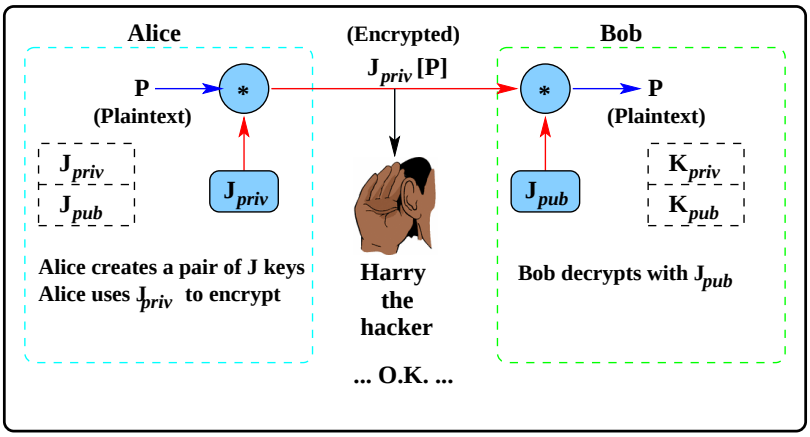
- Participants each have private and public keys
- Keys cannot be derived from each other

Asymmetric encryption



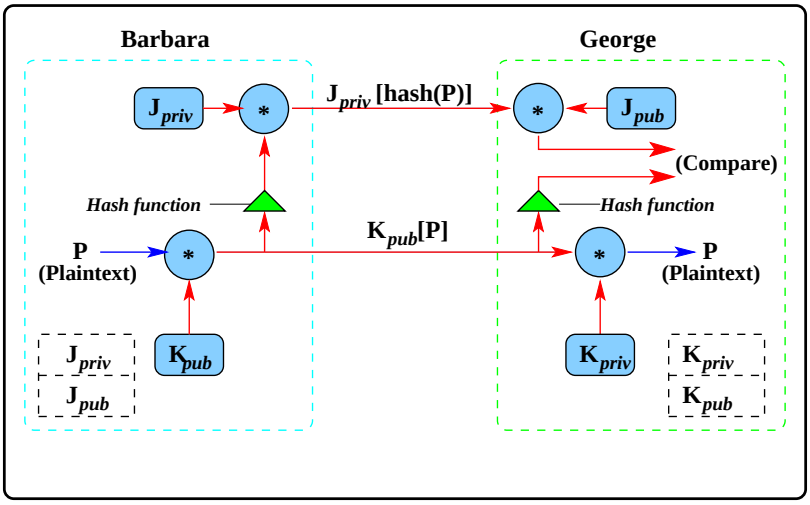
- K_{pub} is public key for Bob, K_{priv} is his private key.
- Only Bob can decrypt

Asymmetric authentication



- J_{priv} is private key for Alice, J_{pub} is her public key.
- Only Alice could have encrypted message

Authentication and encryption



- Making sure of digital signatures. Hash function...

RSA (Rivest, Shamir, Adelman)

This public key system relies on the difficult problem of trying to find the complete factorization of a large composite[14] integer whose prime factors[15] are not known.

[14] An integer larger than 1 is called *composite* if it has at least one divisor larger than 1.

[15] The *Fundamental Theorem of Arithmetic* states that any integer N (greater than 0) may be expressed uniquely as the product of prime numbers.

RSA hacks

Two RSA-encrypted messages have been cracked:

- The inventors of RSA published a 129-digits (430 bits) RSA public key. In 1994, it was factored with 5000 MIPS-years of computing time.
- A year later, a 384-bit PGP key was cracked. It needed 1300 MIPS-years to factor the key in three months.

Note that these efforts each only cracked a single RSA key.

RSA coding algorithms

Below are outlined the four processes needed for RSA encryption:

1. Creating a public key
2. Creating a secret key
3. Encrypting messages
4. Decoding messages

To create public key K_p

1. Select two different large primes P and Q.
2. Assign $x = (P-1)(Q-1)$. (Does this ring a bell?)
3. Choose E relative prime to x. (This must satisfy condition for K_s given later)
4. Assign $N = P * Q$.
5. K_p is N concatenated with E.

To create private (secret) key K_s

1. Choose D: $D * E$ **mod** $x = 1$.
   (a) (i.e. multiplicative inverses)
   (b) another way: $DE = k(P-1)(Q-1)+1$
2. K_s is N concatenated with D.

To encode plain text m

1. Pretend m is a number.
2. Calculate $c = m^E$ **mod** N.

To decode c back to m

1. Calculate $m = c^D$ **mod** N.
2. ....WHY?....

...Why?...

$$
\begin{aligned}
c^D \bmod N &= m^{ED} \bmod N \\
&= m^{k(P-1)(Q-1)+1} \bmod PQ \\
&= m * m^{k(P-1)(Q-1)} \bmod PQ \\
&= m
\end{aligned}
$$

- $m^{P-1} \bmod P = 1$, so $(m^{(P-1)})^{k(Q-1)} \bmod P = 1$
- $m^{Q-1} \bmod Q = 1$, and so (tutorial) $(m^{(P-1)})^{k(Q-1)} \bmod PQ = 1$.

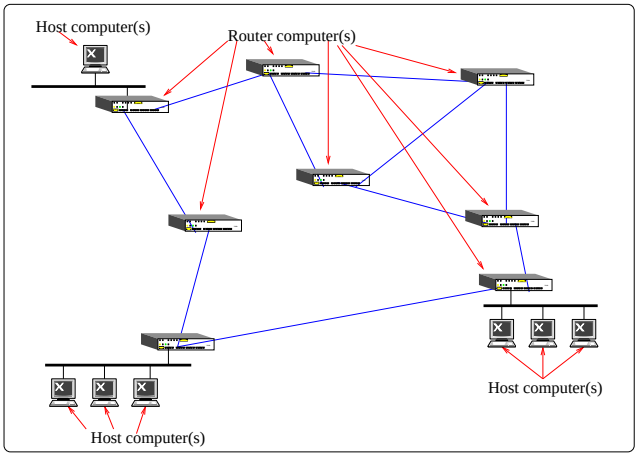
RSA code

```
#!/usr/bin/perl -sp0777i<X+d*lMLa^*lN%0]dsXx++lMlN/dsM0<j]dsj
$/=unpack('H*',$_);$_='echo 16dio\U$k"SK$/SM$n\EsN0p[lN*1
lK[d2%Sa2/d0$^Ixp"|dc';s/\W//g;$_=pack('H*',/((..)*)$/)
```

and then

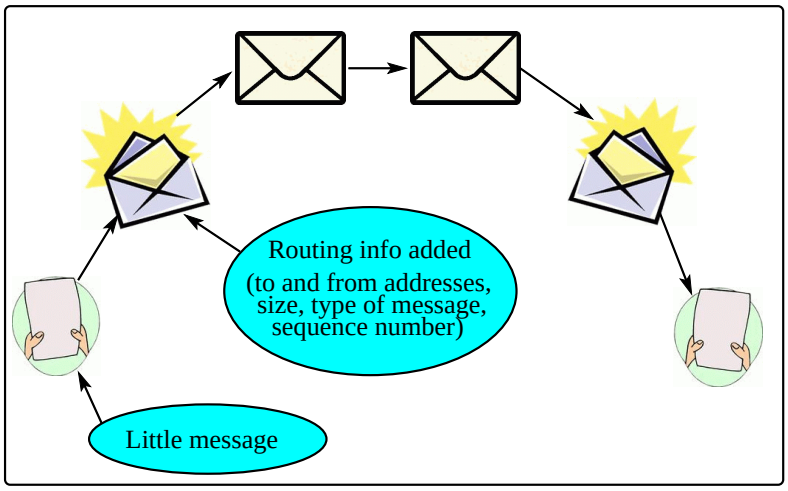
- `echo "squeamish ossifrage" | ./rsa.perl -k=10001 -n=1967cb529 > msg.rsa`
- `./rsa.perl -d -k=ac363601 -n=1967cb529 < msg.rsa`

New topic: Protocols...



- Lots of opportunity to snoop, modify, DoS, etc etc

Routing and packets...



- Lots of opportunity to modify routing information, spoof etc etc

Kerberos/Cerberus

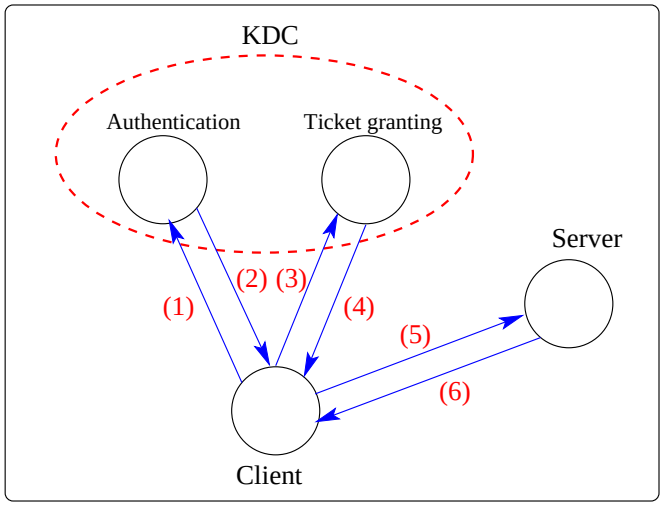
Kerberos

- ✔ Network ***authentication*** protocol.
- ✔ Strong authentication for client/server applications using public key cryptography.
- ✔ Kerberos is freely available in source form
- ✔ Kerberos is also available in commercial products.
- ✔ Client can prove its identity to a server (and vice versa) across an insecure network connection.

Kerberos

- ✔ After a client and server have used Kerberos to prove their identity, they can also encrypt all of their communications to assure privacy and data integrity as they go about their business.
- ✔ Must have a Key Distribution Center (KDC)
- ✔ Kerberos uses Needham-Schroeder protocol.

Kerberos



Kerberos

When a client first authenticates to Kerberos, she:

1. Talks to KDC, to get a *Ticket Granting Ticket*
2. Uses that to talk to the *Ticket Granting Service*
3. Uses the ticket, to interact with the server.

This way a user doesn't have to reenter passwords every time they wish to connect to a Kerberized service. If the Ticket Granting Ticket is compromised, an attacker can only masquerade as a user until the ticket expires.

Kerberos protocol

- ✔ Two sorts of credentials: ***tickets*** and ***authenticators***.
- ✔ A *ticket* $T_{c,s}$ contains the client's name and network address, the server's name, a timestamp and a session key. This is encrypted with the server's secret key (so that the client is unable to modify it).
- ✔ An *authenticator* $A_{c,s}$ contains the client's name, a timestamp and an optional extra session key. This is encrypted with the session key shared between the client and the server.

Kerberos protocol

- ✔ A *key* $K_{x,y}$ is a session key shared by both x and y.
- ✔ When we encrypt a message M using the key $K_{x,y}$ we write it as $\{M\}K_{x,y}$.

Kerberos protocol

Alice wants session key for communication with Bob:

- ✹ Alice sends message to Ted containing her identity, Ted's TGS identity, and one-time value (n) : $\{a, tgs, n\}$.
- ✹ Ted responds with a key encrypted with Alice's secret key (which Ted knows), and a ticket encrypted with the TGS secret key: $\{K_{a,tgs}, n\}K_a$ $\{T_{a,tgs}\}K_{tgs}$.
  Alice now has ticket and session key: $\{T_{a,tgs}\}K_{tgs}$, $K_{a,tgs}$
- ✹ Alice can prove her identity to the TGS, as she has session key $K_{a,tgs}$, and *Ticket Granting Ticket*: $\{T_{a,tgs}\}K_{tgs}$.

Kerberos protocol

Later, Alice can ask the TGS for a specific service ticket:

- When Alice wants a ticket for a specific service (say with Bob), she sends an *authenticator* along with the *Ticket Granting Ticket* to the TGS: $\{A_{a,b}\}K_{a,tgs}\ \{T_{a,tgs}\}K_{tgs}, b, n$.
- The TGS responds with a suitable key and a ticket: $\{K_{a,b}, n\}K_{a,tgs}\ \{T_{a,b}\}K_b$.
- Alice can now use an authenticator and ticket directly with Bob: $\{A_{a,b}\}K_{a,b}\ \{T_{a,b}\}K_b$.

Weaknesses

Host security: Kerberos makes no provisions for host security; it assumes that it is running on *trusted* hosts with an *untrusted* network.

KDC compromises: Kerberos uses a principal's password (encryption key) as the fundamental proof of identity.

Salt: This is an additional input to the one-way hash algorithm.

Voting protocols

A voting protocol is one in which

- independent systems vote in a kind of election, and
- afterwards we can check that the vote was correct.
- Each voter is only allowed a single vote, and
- the system should be corruption-proof.

Voting protocols

Example with Alice, Bob and Charles (!), who vote and then encrypt and sign a series of messages using public-key encryption. For example, if Alice votes v_A, then she will broadcast to all other voters the message

$$R_A(R_B(R_C(E_A(E_B(E_C(v_A))))))$$

where R_A is a random encoding function which adds a random string to a message before encrypting it with A's public key, and E_A is public key encryption with A's public key.

Voting protocols

- ✔ Each voter then signs the message and decrypts one level of the encryption.
- ✔ At the end of the protocol, each voter has a complete signed audit trail and is ensured of the validity of the vote.

Tossing a coin

- ✔ Alice and Bob want to toss a coin
- ✔ Alice calculates two primes p, q and calculates $N = pq$, sends N to Bob. $N = 35 = 5 * 7$
- ✔ If Bob can factorize the number, then Bob wins a coin toss.
- ✔ Bob selects random x, and sends $x^2 \bmod N = y$ to Alice. $y = 31^2 \bmod 35 = 16$

Tossing a coin

Alice calculates the four square roots of 16:

- 4^2 mbox $35 = 16$
- 31^2 mbox $35 = 16$
- 24^2 mbox $35 = 16$
- 11^2 mbox $35 = 16$

This is easy for Alice, as she knows the prime factors of N. She then sends one of these back to Bob.

Tossing a coin

- ✔ If Bob receives x or $-x$, then he learns nothing, but
- ✔ if Bob receives either of the other values, he can add this to x, and then find the GCD of the result with N:

$$\begin{aligned} \text{GCD}(24+31, 35) &= \text{GCD}(55, 35) \\ &= 5 \end{aligned}$$

- ✔ Alice is unable to tell she has divulged the factor

Oblivious transfer

- ✔ In an oblivious transfer, randomness is used to convince participants of the fairness of some transaction
- ✔ In a coin-tossing example, Alice knows the prime factors of a large number, and if Bob can factorize the number, then Bob wins a coin toss.
- ✔ A protocol allows Alice to either divulge one of the prime factors to Bob, or not, with equal probability.
- ✔ Alice is unable to tell if she has divulged the factor, and so the coin toss is fair.

Contract signing

- ✔ Signing contracts can be difficult.
- ✔ If one party signs the contract, the other may not. We have one party bound by the contract, and the other not.
- ✔ In addition, both may sign, and then one may say "*I didn't sign any contract!*" afterwards.

Contract signing

Oblivious transfer used for contract-signing where

- Up to a certain point neither party is bound
- After that point both parties are bound
- Either party can prove that the other party signed

Alice and Bob exchange signed messages, agreeing to be bound by a contract with ever-increasing probability

Contract signing

- ✔ In the event of early termination of the contract, either party can take the messages they have to an adjudicator, who chooses a random probability value (42% say) before looking at the messages.
- ✔ If both messages are over 42% then both parties are bound.
- ✔ If less then both parties are free.