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Cryptology, Cryptography, and Cryptoanalysis - Past, Present and Future Role in Society

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Abstract: **This article provides a general introduction to the subject of Cryptology, Crytography and Crytoanalysis and explains the terminology, mathematical interpretations and the practical applications of security techniques….**

Aims & Scope: In recorded History, technological innovations have revolutionized societies. The printing press is an often-cited example of the great impact one humble person's invention can have on ruling dynasties, world religions, and personal life..Quantum encryption could rival Guttenberg's printing press in its impact. Cryptology has a fascinating History.,In Warfare Cryptography is a broad, sticky, and mathematically complex, but interesting subject and an integral part of the evolution of warfare. So let's get some definitions out of the way first. Cryptology is the study of codes, both creating and solving them. Cryptography is the art of creating codes. Cryptanalysis is the art of surreptitiously revealing the contents of coded messages, breaking codes, that were not intended for you as a recipient.. Secondly, there are nomenclators and enciphers. Nomenclators are letters or numbers that represent words or phrases, like 103A means "meet me at 4PM". Ciphers are alphabetical letters or numbers that are encrypted using some sequential coding process and a key. For this essay, we will refer to both as codes. Also, enciphered, encrypted and encoded mean the same thing….Additionally, there is plain text. This is the original message that is readable and understandable, uncoded or unencrypted. Once it goes through the coding process and is encrypted, the output is readable but not understandable. There are a bunch of other terms like steganography, homophones, polyphones, digraphs, bigrams, and polygrams, but they are just variations of coding and decoding techniques.

Keywords: **Network Protocols, Mathematical Cryptology, Encryption, Decription, Codes. PKI Infrastructure.**

INTRODUCTION

i) Cryptology:- The study of cryptography and cryptanalysis. .Cryptology is the mathematics, such as number theory, and the application of formulas and algorithms, that underpin cryptography and cryptanalysis. cryptology is made up of cryptographyand cryptanalysis.

ii) Crytography- The art and science of making ciphers. Cryptography is the process of writing using various

methods ("ciphers") to keep messages secret.which concerns with the design of the cryptosystems and cryptography, is the actual securing, control, and identification of digital data. Since the cryptanalysis concepts are highly specialized and complex, we concentrate here only on some of the key mathematical concepts behind cryptography.

iii) Crytoanalysis—The art and science of breaking ciphers. In other words, the extraction of mm given cc, EE, DD, and possibly keke. ..which aims at studies relating to breaking of cryptosystems. cryptanalysis, is made up of all the attempts one might develop to undermine, circumvent, and/or break what the first part, cryptography, is attempting to accomplish.

iv) Cryptosystems:-A particular suite of algorithms and protocols for encryption, decryption, and key generation. Examples: Cramer-Shoup cryptosystem, Rabin cryptosystem, Benaloh cryptosystem, RSA cryptosystem.

v) Cryptographic System:-Any system that uses cryptography.

vi) Cipher:-An algorithm used in a cryptosystem.

vii) Confusion:-The property of having the relationship between the plaintext, ciphertext, and key so complicated as to be useless to the cryptanalyst.

viii) Diffusion:-The property of having statistical patterns in the plaintext spread widely throughout the ciphertext.

ix) Frequency Analysis

- Known plaintext attack
- Known ciphertext attack
- Chosen plaintext attack
- Chosen key attack
- Linear cryptanalysis
- Differential cryptanalysis
- Theft
- BriberyBlackmail

Basic terminology/notation

- **P** is the plaintext. This is the original readablemessage (written in some standard language, like
- English, French, Cantonese, Hindi, Icelandic, . . .).
- **C** is the Ciphertext. This is the output of some, encryption scheme, and is not readable by humans
- **E** is the Encryption function. We write, for example,- **E(P) = C** to mean that applying the Encryption process **E** to the plaintext **P** produces the Ciphertext **C.**
- **D** is the Decryption function, i.e **D(C) = P.** **Note D[E(P)] = P and E[D(C)] = C.**

What tools use cryptography?Some form of cryptography can be found nearly everywhere in computer technology. Popular standalone programs, like PGP and GPG, aid in securing communications. Web browsers and other programs implement cryptographic layers in their channels. Drivers and programs exist to secure files on disk and control access thereto. Some commercial programs use cryptographic mechanisms to limit where their installation and use may occur. Basically, every time you find a need to control the access and usage of computer programs or digital data, you'll find that cryptographic algorithms constitute important parts of the protocol for use of these programs/data.

A little history:-Cryptology, the study of coded messages, dates back to Egypt about 1,900 BC, when a scribe carved some hieroglyphic symbols into a rock at the tomb of Khnumhotep II. Cryptology wasn't that hard back then, since most of the people were illiterate and only the elite could read any written language. Pharaohs and potentates, kings and queens, presidents and dictators, and military commanders have used cryptology to hide their communications from their enemies ever since. An interesting example is Mary, Queen of Scotts. In 1577, Don Juan, ruler of Austria, had worked out a plan to invade England, dethrone and kill Queen Elizabeth, put Mary on the throne, and marry her. But, Elizabeth's minister, Francis Walsingham, smelled a rat and had Mary confined to castles away from ElizabethMary's page, Antony Babington, began plotting to have Elizabeth assassinated 1586, with the help of Don Juan and Phillip, the king of the Netherlands. Babington employed Gilbert Gifford to smuggle encrypted communications between him and Mary out of the castle in beer barrels. As it turns out, Gifford was an agent working for Walsingham, so those messages got delivered to him immediately. He employed Thomas Phelippes to decrypt those messages which thoroughly incriminated Mary of plotting to kill Elizabeth, and she was convicted of high treason. So, at 8AM on the morning of 8 February 1587, the executioner chopped off Mary's head with an axe. Such is the importance of insuring your code is hard to break. Thomas Philippes became England's first cryptanalyst, establishing the role of codebreakers in the future.

Code types:-There are numerous types of codes throughout history: mono-alphabetic, poly-alphabetic, columnar transposition, S-boxes and P-boxes, Polybius squares, etc. Many primitive machines were made to encrypt/decrypt messages. One of the first used a wooden dowel about an inch in diameter and two feet long. A 1/4 inch-wide piece of parchment, about 3 feet long, was wrapped around the dowel, edge to edge like a barber pole. The plaintext message was then written vertically on the dowel in columns. When unraveled from the pole and laid out flat, it would look like a series of letters on a strip of paper that made no sense. Only when the intended recipient wrapped the 1/4 inch strip of parchment

around his 1-inch wooden dowel could the characters be read in the proper order, vertically. Other early mechanisms used were identical cipher wheels and cypher drums held by both the sender and receiver. Other codes used simple key words shared by two people, and an agreement on how the code would be structured. That could be worked out mentally on paper, without the use of a mechanical mechanism. As you can see, many early codes and code machines were cumbersome and it took a lot of time to encrypt or decrypt a message…Although the early codes were unsophisticated and primitive, they taught many lessons. The first is that the only people with the knowledge to create secure codes are the cryptanalysts: they know the weaknesses of the codes they have already broken. The second lesson is that the most important element of a code is the key: it does not matter if your enemy knows how your code is structured if you have complex keys. Third, the longer your key, the more difficult your code is to break. If your key is the same length as your message, your message is basically unbreakable. But, as early cryptographers have stated, no code is unbreakable. Fourth, the longer your message, the easier it is to break. And finally, always send the message in five-letter groups, to hide the number and length of words.

Externals and internals: There are two parts to any encrypted message: the externals, and the internals. Cryptanalysis must discover the internals, the process by which the encrypted message was created, by using the external characteristics of the message. The first technique is character frequency analysis. The National Security Agency (NSA) has run millions of pages of newspapers, books, periodicals, and magazines through their computers, establishing the letter frequency charts of the English language: these are the percentages of each letter in a page of text: a= 8.167 percent, e= 12.702 percent, i=6.966 percent, o=7.507 percent, u=2.758percent, and so on. With an encrypted message using a simple substitution code where x=e, z=a, etc, it's child's play to decrypt it just using the character frequency tables. Our intelligence people have such tables for all the significant languages on the planet.

Next is the first-letter-of-a-word frequency charts: we know the frequencies of which letter the words start with in a page of text (a=11.602 percent, b=4.702 percent, etc). Then, there's letter proximity charts: TT, CC, QU, TH, CH, ING, ION, ED, and ON all string together regularly, and we know what percentage of words have those frequencies. There are also word frequency charts: AND, CAN, IS, IF, OF, WITH, OVER, UNDER, ABOUT, and other word frequencies are well known. Also, a cryptanalyst can make letter interval charts, the distance between letters in the encrypted message. If an M appears in the encrypted message twice, and they are 12 letters apart, then the keyword is probably either 6 characters or 12 characters long (since 3 and 4 character keys are not very secure). This is a process called "key discovery through symmetry of position". There are additional frequency and interval analysis tools, too many to recount here, that can reveal how an encrypted message was constructed.

Once a good cryptanalyst applies the externals analysis tools, recovers the key, and decrypts the message, he can then reconstruct the encryption process used for that message. That process, and the key, are the internals of the code. Also, once we have the patterns for the externals of a certain code, we can analyze thousands or millions of other intercepted encrypted messages against that known pattern, to see if they fit. If they do, we know the internals of the code, so it's just a matter of using letter interval charts to uncover the symmetry of position of the letters in the encrypted message, retrieve the key, and decrypt them.

NSA efforts : In 1969, there were 96,000 people working for the NSA, including my old Army Security Agency (ASA) unit, that were intercepting enemy messages, running the frequency/proximity/symmetry charts against those messages, decrypting them, analyzing them, cataloging them, and disseminating the intelligence to our military commanders. Today, that process is done with acres of NSA supercomputers discussed in the previous installment of this warfare series. Now you know why NSA has the most computing power on the planet.With massive amounts of computer power, relatively sophisticated codes can be broken in a short time with these brute-force methods. Today's advanced codes, like Logarithmic and Elliptical coding schemes, are very secure but not unbreakable. It takes millions of years for our computers to discover the two prime numbers multiplied together to create a 200-digit key used for encrypting a message. A quantum computer can do it in an hour, according to cryptanalysts, which is why NSA has been funding quantum computer research and development since the 90's. Turn that decryption concept around, and quantum computers could create massive keys, as long as the message itself, that make them invulnerable to cryptanalysis techniques and decoding by our enemies. AugusteKerckhoffs, the author of La Cryptographiemilitaire, once said, "…secrecy must reside solely in the keys." As you can see from the examples of frequency analysis above, all encrypting techniques and their resulting coded messages, have certain idiosyncrasies or patterns that offer a good cryptanalyst a crack to get his fingers into. With a bit of work, by him or computers, he can widen that crack and get inside, recover the keys and the coding scheme, and break it.

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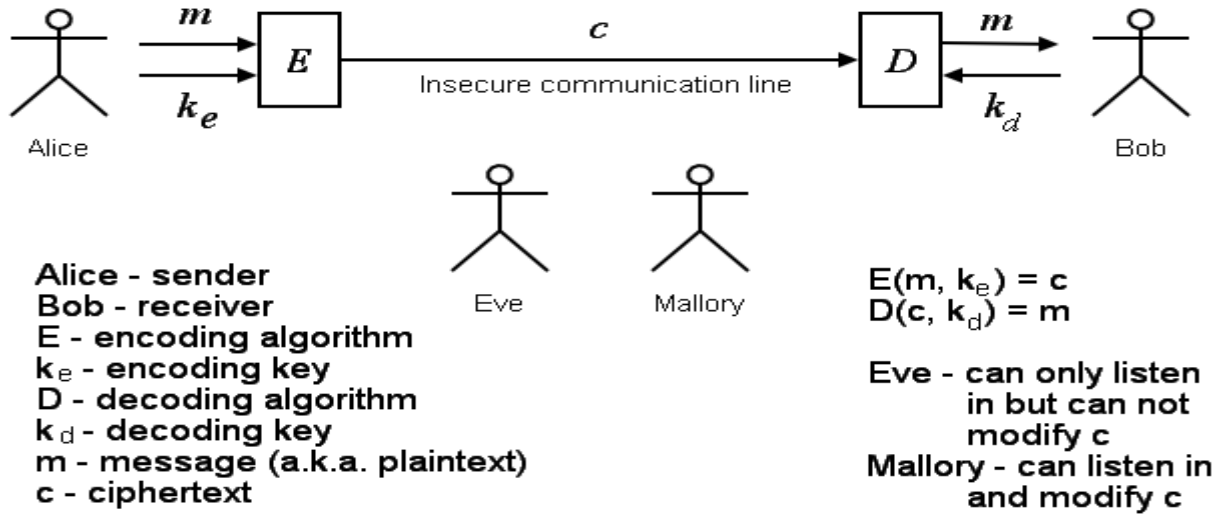
Time shifting:-If quantum cryptology doesn't impress you, let's explore doing time shifting. The scientists at Purdue University have figured out how hide data in a light beam. They take two beams and modulate them slightly out of phase with each other on an optical fiber. That creates "holes in time", between the two beam phases. Into that hole, they drop the plaintext data. If you look at the modulated beam, you see a flat line, no light, where the data is now located. The receiver, knowing the modulation patterns, can simply demodulate the beam and recover the data. The modulation patterns are the key to the encoding scheme. For many years, computers have been doing the in-stream encryption and decryption for our military and government communications. That makes the process fast and secure. When the Pueblo was captured by the North Koreans in January 1968, the President of the United States knew about it within a few minutes via secure encrypted communications from ASA intelligence people in the Pacific to NSA at Fort Meade…. The Pueblo had top secret crypto machines onboard, the same models used by NSA and ASA, and the North Koreans grabbed them intact (they shared them with the Russians too). Did the U.S. intelligence groups have to throw away all the crypto machines and replace them with new ones? No. All we had to do was change the keys and the captured machines were basically worthless to the North Koreans and the Russians. So, Kerckhoffs was correct: the keys are the key.If you want to dig deeper into this topic, the best book on the history of cryptology is "The Codebreakers" by David Kahn (if you can find a copy). It's over 1,000 pages long but worth a read. The chapters about breaking the German Enigma machines and the Japanese Purple code in WWII are astonishingly detailed. If you want to understand basic encryption techniques and more history, read "The Code Book" by Simon Singh. If you are not mathematically challenged, read "Cryptanalysis" by Helen Fouche Gaines. Same goes for "Decrypted Secrets" by F. L. Bauer, very heavy on formulas. And finally, there's the ever-popular "Modern Cryptanalysis" by Christopher Swenson (this is a text book with exam questions, problems to solve, and software examples in Python, so you can program your analysis techniques into your computer). I'll warn you now: these books are not light reading.For our next installment, we will take a look at the military capabilities of our closest enemies, through the eyes of our intelligence folks. That will give you an informed idea of where we stand in a war with any of them.

Background



Gool for use of these programs/data…

Goals:

- **Confidentiality**: It should cost Eve more to recover mm than mm is worth.
- **Authentication**: Bob should be able to verify that it was Alice that sent mm.
- **Integrity**: Bob should be able to verify that mm was not tampered with.
- **Non repudiation**: Alice should not be able to deny sending mm.

The best cryptosystems assume that Eve and Mallory know EE, DD, cc, and, if ke≠kdke≠kd, then keke as well. Most cryptosystems do **not** rely on their algorithms being kept secret, because:

- If your secret algorithm is compromised (someone could leave your group), you have to change it, and that is way harder than just changing a key!
- Public algorithms can be subjected to thousands of experts looking for flaws, so you have some degree of confidence in those that withstand scrutiny.

The study of cryptology includes the design of various ciphers, cryptanalysis methods (attacks), key exchange, key authentication, cryptographic hashing, digital signing, and social issues (legal, political, etc.).

Protocols and algorithms

When considering cryptology, it is important to make the distinction between protocols and algorithms. This is especially important in light of the misleading claims sometimes made by companies that produce cryptographic products (either out of carelessness or misrepresentation). For example, a company might claim: "If you use our product, your data is secure because it would take a million years for the fastest computers to break our encryption!" The claim can be true, but still not make for a very good product. A true claim about the strength of an algorithm by itself does not necessarily mean that a whole protocol that uses that algorithm as one of its steps does not have other weaknesses.

A protocol is a specification of the complete set of steps involved in carrying out a cryptographic activity, including explicit specification of how to proceed in every contingency. An algorithm is the much more narrow procedure involved in transforming some digital data into some other digital data. Cryptographic protocols inevitably involve using one or more cryptographic algorithms, but security (and other cryptographic goals) is the product of a total protocol.

Technological Background:- There are two basic types of encryption commonly used today, symmetric key and asymmetric key encryption. Although the two methods are very different in theory and application, similar terminology is used to describe the processes:

Plaintext: The data or message to be sent, in a clear form anyone can read.

Ciphertext: The data in encrypted form.

Bit: Binary digit, the basic unit of information stored by a computer. Any letter or number can be encoded as a string of 8 bits.

Algorithm: The method used to encrypt and decrypt data, also called a “Cipher.”

Key: A crucial parameter in the algorithm.

Hash: A fingerprint for a digital file.

Alice and Bob: Alice is trying to send Bob a message over an insecure channel. Eve wants to eavesdrop.

Attack: A method that can decrypt the message for an interceptor.

Shannon’s Maxim: The enemy knows the system! A secure algorithm must assume the enemy knows everything about the system except the key. The goal of this section is to provide a brief overview of how ciphers work and the history of cryptography. The scope includes everything from World War I and excludes the field of classical cryptography. Symmetric Key Encryption:- Symmetric key encryption is the older and better-known technique. At its most primitive, the algorithm could be “shift each letter alphabetically” and the key could be “+2.” Therefore, the Alice will simply shift each letter by 2 spaces to convert plaintext to ciphertext, and Bob will simply shift back 2 spaces to decrypt the message.

For example: Plaintext: MARK IS A SPY

Alice shifts each letter +2: OCTM KU C URA

Bob shifts each letter -2: MARK IS A SPY

There are three characteristics of this simple exercise that also hold true for even the most complex symmetric key algorithms:

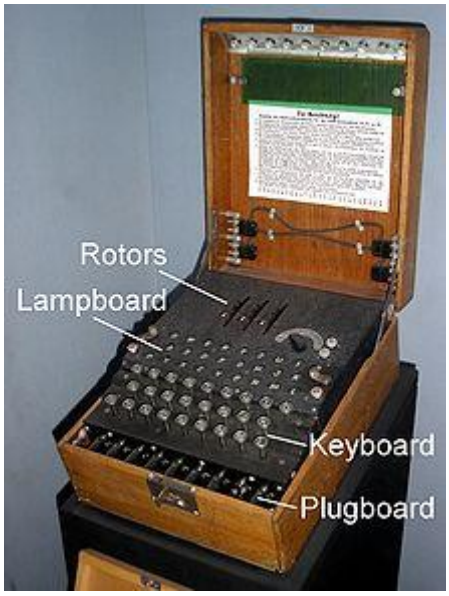
Alice and Bob use the same key to both encrypt and decry.

The method is useless if they key is not kept privately between Alice and Bob, which is whythis method is sometimes referred to as private key encryption.

Alice must first securely notify Bob of her keyThe last characteristic is the method's greatest limitation. The key, which must be sent in plaintext, can be intercepted. Overcoming or exploiting this weakness is a reoccurring theme in this report and also a focus of cryptographic research. Examples of Symmetric Key I present four examples to illustrate symmetric key cryptography: Enigma: Historical yet fascinating example

- One-time Pad: Unbreakable but hard to implement
- Stream Cipher: Vulnerable yet still foolishly used.
- Block Cipher: The current industry standard in security.

Enigma: The **Enigma machines** are a series of electro-mechanical rotor cipher machines, mainly developed and used in the early- to mid-20th century to protect commercial, diplomatic and military communication. Enigma was invented by the German engineer Arthur Scherbius at the end of World War I. . Early models were used commercially from the early 1920s, and adopted by military and government services of several countries, most notably Nazi Germany before and during World War II Several different Enigma models were produced, but the German military models, having a plugboard, were the most complex. Japanese and Italian models were in use:



Kinds of Ciphers

Here are some useful categories of ciphers. Note that a particular cipher may belong to more than one of these categories.

- Classical (a.k.a. manual): A cipher easy enough to be performed by hand, usually character-based
- Modern: Pretty much any cipher that isn't classical
- Substitution: Each character of the plaintext is replaced with one or more characters to make the ciphertext
- Transposition: Characters in the plaintext are rearranged to form the ciphertext
- Monoalphabetic: A substitution cipher in which a character of the plaintext is always replaced by the same character
- Polyalphabetic: A substitution cipher that essentially uses multiple monoalphabetic substitution mappings
- Homophonic: A substitution in which one character can map to one of a set of characters
- Polygraphic: A substitution of blocks of characters for blocks of characters
- Periodic: A polyalphabetic cipher in which the replacement scheme repeats

- Non-periodic: (Self-explanatory if you understand periodic)
- Block: Encryption takes place not per character but per blocks of characters.
- Stream: A cipher operating on a data stream of unknown length, usually incorporating feedback.
- Secret Key: A cipher in which keke and kdkd are the same or trivially derivable from one another; requires the parties to meet in secret to exchange the keys they'll be using. Also called *symmetric*.
- Public Key: A scheme in which everyone's encryption key is publicly known but their decryption key is kept secret. Also called *asymmetric*.

NOTE: In the character-based examples below, we'll assume (without any loss of generality) a 26 symbol alphabet (A..Z).

Secret Key Cryptography

Secret key (a.k.a. symmetric key) ciphers are much faster than public key ciphers, but key management can be a huge problem.

- If n people in a group need to communicate, they need $n(n-1)/2$ keys.
- Keys must be distributed securely (in secret).
- Keys must be kept safe.
- Keys should be changed frequently, which feeds back into the distribution headache.

Caesar Cipher:- A completely pathetic and insecure cipher by modern standards. The encryption key keke is a small integer and kd=ke◂=▸kd=ke. To encrypt, add keke to each plaintext character; to decrypt, subtract.

Example: For k=5, ATTACKATDAWN becomes FYYFHPFYIFBS

Trivial to crack: just guess k_e.

Monoalphabetic Substitution

Instead of simply adding a fixed offset to each character, you can precompute a substitution table by generating a random permutation of your alphabet. For example:

ABCDEFGHIJKLMNOPQRSTUVWXYZ

MQHPSVJYCURFTBILAKWNGZDOEX

Now ATTACKATDAWN is now MNNMHRMNPMDB.

You don't crack this by guessing the key (there are n!n! possible keys), but frequency analysis can crack any monoalphabetic substitution cipher, provided the message is long enough.

For techniques whose key is a permutation, one way to make the key easier to remember is to pick a phrase, lay out its unique letters, then fill in missing letters in order. For example, PREMATURE OPTIMIZATION IS THE ROOT OF ALL EVIL yields this substitution mapping:

PREMATUOIZNSHFLVBCDGJKQWXY

Homophonic Substitution

Each plaintext letter maps to one or more symbols in the ciphertext. The number of targets should be proportional to its frequency (to defeat frequency analysis). Example:

A 12 15 36 50 56 70 81 95

B 51 84

C 16 44 65

D 04 06 48 82

E 01 17 19 34 47 49 58 60 67 77 85 90

F 13 27

G 09 28

H 26 42 53 59 68 71

I 35 73 76 86 91 96

J 18

K 07

L 29 40 54 87

M 25 30

N 21 61 62 69 74 94

O 02 03 08 10 57 75 93

P 41 98

Q 97

R 32 38 43 45 80 83

S 14 22 39 79 89 99

T 00 20 23 33 46 52 72 78 88

U 11 64 66

V 37

W 63 92

X 31

Y 24 55

Z 05

To encrypt, choose randomly among possibilities. Example, one possible encryption of ATTACKATDAWN is

56 78 20 95 65 07 12 72 06 50 92 61

Modern Auto-Key Ciphers

You can still crack autokeyVigenère ciphers by linguistic analysis, because the key contains text and is thus likely to have high-frequency letters. Modern auto-key ciphers generate the shift values with a random number generator. The key seeds the generator.

Modern Cryptographic Methods:-Now that we have Shannon's information theory, very powerful computers, and centuries of theory and practice behind us, most modern techniques

- operate on bit strings, not character strings
- are careful to completely mask patterns and redundancies in the plaintext
- use random keys (that can be reused, too)
- ensure that very slight changes in the plaintext affect a large portion of the ciphertext (and vice versa). This is called the Avalanche Effect.In addition, it's nice if the cipher is efficientfault- tolerant

Most ciphers are either block ciphers or stream ciphers. Block ciphers require padding and can operate in different **modes** (See Schnier's book or the Wikipedia article:

- ECB — Electronic Codebook
- CBC — Cipher Block Chaining
- CFB — Cipher Feedback
- OFB — Output Feedback
- CTR — Counter
- BC — Block Chaining
- PCBC — Propagating Cipher Block Chaining
- CBCC — Cipher Block Chaining with Checksum

DES, IDEA, RC4, RC6

Blowfish

Twofish

AES:- AES is the new standard, replacing DES. It was the winner of the competition (in 2001), where is was submitted under the name Rijndael, beating out RC6, Serpent, MARS, and Twofish.

Politics, Ethics, Privacy

Key Exchange

Diffie and Hellman (the 2015 Turing Award Winners) and their friend Merkle showed in 1976 that it was possible for two people to exchange a secret key *without having to actually meet in secret*:

- Alice picks a prime nn and sends this in the clear to Bob
- Alice picks a primitive root mod nn (how to find), called g, and sends this in the clear to Bob
- Alice picks a secret integer a, and sends gamodn in the clear to Bob
- Bob picks a secret integer bb, and sends gbmodn in the clear to Alice
- Alice computes (gbmodn)aand Bob computes (gamodn). This is the key! (It's gabmodn)

This is probably secure, provided nn is very large and n−12n−12 is also prime, because although Eve knows gg, nn, gamodngamodn, and gbmodngbmodn, there's no known efficient way to get aa or bb from these. That's the discrete logarithm problem, remember?

Example with small nn:

- Alice picks n=208799n and g=13 and sends these to Bob
- Alice picks a=152335 and Bob picks b=98113
- Alice sends Bob 13^152335 mod 208799 =73033
- Bob sends Alice 13^98133 mod 208799=147540
- Alice computes 147540 ^ 152335 mod208799= 8435
- Bob computes 73033^ 98133 mod208799=8435

The secret key is 84358435.

Public Key Cryptography

Public key cryptography is a cryptographic technique that enables entities to securely communicate on an insecure **public network**, and reliably verify the identity of an entity via digital signatures…Public key ciphers solve the key management nightmare of secret key ciphers, at the cost of speed. In a group of n people one needs only n public keys and n private keys…The Public key infrastructure (PKI) is the set of hardware, software, policies, processes, and procedures required to create, manage, distribute, use, store, and revoke digital certificates and public-keys. The PKI is the foundation that enables the use of technologies, such as digital signatures andencryption, across large user populations. PKIs deliver the elements essential for a secure and trusted business environment for e-commerce and the growing Internet of Things (IoT)… PKIs help establish the identity of people, devices, and services – enabling controlled access to systems and resources, protection of data, and accountability in transactions. Next generation business applications are becoming more reliant on public key infrastructure (PKI) technology to guarantee high assurance as evolving business models are becoming more dependent on electronic interaction requiring online authentication and compliance with stricter data security regulations..

Cryptographic Security:-Using the principles of asymmetric and symmetric cryptography, PKIs facilitate the establishment of a secure exchange of data between users and devices – ensuring authenticity, confidentiality, and integrity of transactions. Users (also known as "Subscribers" in PKI parlance) can be individual end users, web servers, embedded systems, connected devices, or programs/applications that are executing business processes. Asymmetric cryptography provides the users, devices or services within an ecosystem with a key pair composed of a public and a private key component. A public key is available to anyone in the group for encryption or for verification of a digital signature. The private key on the other hand, must be kept secret and is only used by the entity to which it belongs, typically for tasks such as decryption or for the creation of digital signatures.

The Increasing Importance of PKIs:- With evolving business models becoming more dependent on electronic transactions and digital documents, and with more Internet-aware devices connected to corporate networks, the role of a public key infrastructure is no longer limited to isolated systems such as secure email, smart cards for physical access or encrypted web traffic. PKIs today are expected to support larger numbers of applications, users and devices across complex ecosystems. And with stricter government and industry data security regulations, mainstream operating systems and business applications are becoming more reliant than ever on an organizational PKI to guarantee trust.

RSA Cryptosystem

Diffie-Hellman doesn't do encryption; it just exchanges a key. RSA can encrypt and decrypt. Here's how. ..

Each personGenerates two large primes, p and q.

Publishes his or her public key (N,e) where N=pq.

Computes d = modular inverse of e relative to $(p-1)(q-1)$, keeping it secret.

Destroys p and q.

Now check this out:

For Alice to send a message m to Bob, she sends $c=m^e \bmod N$.

Bob decodes this easily because $m=c^d \bmod N$.

RSA algorithm is asymmetric cryptography algorithm. Asymmetric actually means that it works on two different keys i.e. Public Key and Private Key. As the name describes that the Public Key is given to everyone and Private key is kept private.Let us learn the mechanism behind RSA algorithm :

Generating Public Key :

Select two prime no's. Suppose P = 53 and Q = 59.

Now First part of the Public key :n = P*Q = 3127.

- We also need a small exponent say e :

But Must be

- An integer.
- Not be a factor of n.

Generating Private Key: We need to calculate Φ(n) :

- Such that Φ(n) = (P-1)(Q-1)
- so, Φ(n) = 3016
- Now calculate Private Key, d :
- d = (k*Φ(n) + 1) / e for some integer k
- For k = 2, value of d is 2011.
- Now we are ready with our – Public Key (n = 3127 and e = 3) and Private Key(d = 2011)
- Now we will encrypt "HI" :
- Convert letters to numbers : H = 8 and I = 9
- ThusEncrypted Data c = 89e mod n.
- Thus our Encrypted Data comes out to be 1394
- Now we will decrypt 1394 :
- Decrypted Data = cd mod n.
- Thus our Encrypted Data comes out to be 89
- 8 = H and I = 9 i.e. "HI".

Below is C implementation of RSA algorithm for small values:

filter_noneedit

play_arrow

brightness_4

```
// C program for RSA asymmetric cryptographic
// algorithm. For demonstration values are
// relatively small compared to practical
// application
#include<stdio.h>
#include<math.h>
  // Returns gcd of a and b
intgcd(int a, int h)
{ int temp;
    while (1)
    {temp = a%h;
       if (temp == 0)
         return h;
       a = h;
       h = temp;
   // Code to demonstrate RSA algorithm
int main()
```

```
// Two random prime numbers
double p = 3;
double q = 7;
// First part of public key:
double n = p*q;
// Finding other part of public key.
// e stands for encrypt
double e = 2;
double phi = (p-1)*(q-1);
while (e < phi)
{ // e must be co-prime to phi and
   // smaller than phi.
   if (gcd(e, phi)==1)
      break; elsee++;
 // Private key (d stands for decrypt)
// choosing d such that it satisfies
// d*e = 1 + k * totient
int k = 2;  // A constant value
double d = (1 + (k*phi))/e;
```

- // Message to be encrypted
- doublemsg = 20;
- printf("Message data = %lf", msg);
- // Encryption c = (msg ^ e) % n
- double c = pow(msg, e);
- c = fmod(c, n); printf("\nEncrypted data = %lf", c);
- // Decryption m = (c ^ d) % n
- double m = pow(c, d);
- m = fmod(m, n);
- printf("\nOriginal Message Sent = %lf", m);
- Return 0;
- Output :Message data = 12.000000
- Encrypted data = 3.000000

Original Message Sent = 12.000000

Cryptographic Hashing: Cryptography hash functions play a fundamental role inmodern cryptography. Hash function takes a message as input and produce an output referred to as a hash code, hash-result, hash-value or a simple hash..A hash, a.k.a.fingerprint, checksum, message digest is a bit pattern (usually around 160 bits or so), generated from a message by a cryptographic hash function. For the hash to be secure, or cryptographic, it mustbe computationally

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infeasbile to find a message that hashes to a given value (one wayness)be computationally infeasible to find two messages that hash tothe same value.Usually the change of just a single bit in the message will cause the digest to look completely and totally different.

$ cat will

This is my will.

I leave 1000 dollars to Alice

and everything else to Bob.

Signed, Eve.

$ md5sum will

c18feb890752c9e680c99d1e909fd761 will

$ sed "s/1/9/g" will > Will

$ cat Will

This is my will.

I leave 9000 dollars to Alice

and everything else to Bob.

Signed, Eve.

$ md5sum Will85570bc2d0458b1f98f484261dee7d4d Will see

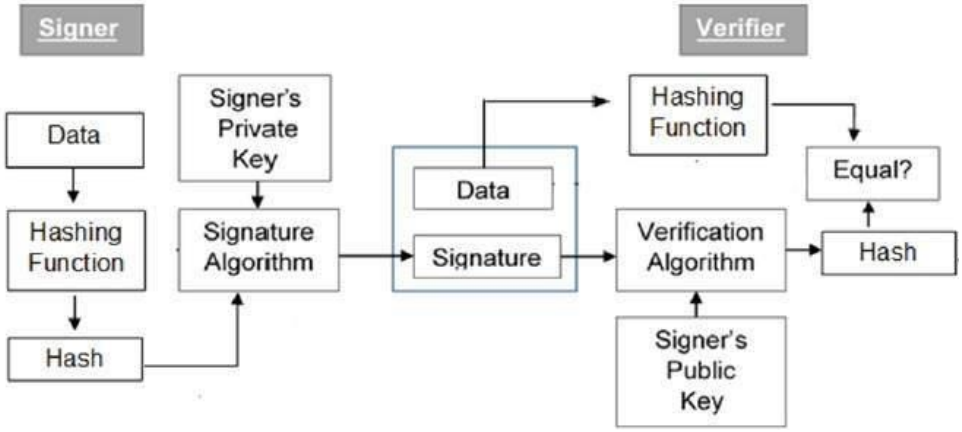
A secure hash provides a way to determine whether a message was tampered with.

Digital Signatures:- A digital certificate is an electronic document issued by aCertificate Authority (CA). It contains the public key for a digital signature and specifies the identity associated with the key, such as the name of an organization. Digital signatures are the public-key primitives of message authentication. In the physical world, it is common to use handwritten signatures on handwritten or typed messages. They are used to bind signatory to the message.

Similarly, a digital signature is a technique that binds a person/entity to the digital data. This binding can be independently verified by receiver as well as any third party.

Digital signature is a cryptographic value that is calculated from the data and a secret key known only by the signer….In real world, the receiver of message needs assurance that the message belongs to the sender and he should not be able to repudiate the origination of that message. This requirement is very crucial in business applications, since likelihood of a dispute over exchanged data is very high.

Model of Digital Signature:- As mentioned earlier, the digital signature scheme is based on public key cryptography. The model of digital signature scheme is depicted in the following illustration



The following points explain the entire process in detail –

Each person adopting this scheme has a public-private key pair.

Generally, the key pairs used for encryption/decryption and signing/verifying are different. The private key used for signing is referred to as the signature key and the public key as the verification key….Signer feeds data to the hash function and generates hash of data.

- Hash value and signature key are then fed to the signature algorithm which produces the digital signature on given hash. Signature is appended to the data and then both are sent to the verifier.

- Verifier feeds the digital signature and the verification key into the verification algorithm. The verification algorithm gives some value as output.

- Verifier also runs same hash function on received data to generate hash value.

- For verification, this hash value and output of verification algorithm are compared. Based on the comparison result, verifier decides whether the digital signature is valid.

Since digital signature is created by 'private' key of signer and no one else can have this key; the signer cannot repudiate signing the data in future..It should be noticed that instead of signing data directly by signing algorithm usually a hash of data is created. Since the hash of data is a unique representation of data, it is sufficient to sign the hash in place of data. The most important reason of using hash instead of data directly for signing is efficiency of the scheme.Let us assume RSA is used as the signing algorithm. As discussed in public key encryption chapter, the encryption/signing process using RSA involves modular exponentiation..Signing large data through modular exponentiation is computationally expensive and time consuming. The hash of the data is a relatively small digest of the data, hence signing a hash is more efficient than signing the entire data.

Importance of Digital Signature:-Out of all cryptographic primitives, the digital signature using public key cryptography is considered as very important and useful tool to achieve information security.

Apart from ability to provide non-repudiation of message, the digital signature also provides message authentication and data integrity. Let us briefly see how this is achieved by the digital signature –

- Message authentication − When the verifier validates the digital signature using public key of a sender, he is assured that signature has been created only by sender who possess the corresponding secret private key and no one else.

- Data Integrity − In case an attacker has access to the data and modifies it, the digital signature verification at receiver end fails. The hash of modified data and the output provided by the verification algorithm will not match. Hence, receiver can safely deny the message assuming th at data integrity has been breached.

- Non-repudiation − Since it is assumed that only the signer has the knowledge of the signature key, he can only create unique signature on a given data. Thus the receiver can present data and the digital signature to a third party as evidence if any dispute arises in the future.

By adding public-key encryption to digital signature scheme, we can create a cryptosystem that can provide the four essential elements of security namely- Privacy, Authentication, Integrity, and Non-repudiation.

Encryption with Digital Signature: In many digital communications, it is desirable to exchange an encrypted messages than plaintext to achieve confidentiality. In public key encryption scheme, a public (encryption) key of sender is available in open domain, and hence anyone can spoof his identity and send any encrypted message to the receiver….This makes it essential for users employing PKC for encryption to seek digital signatures along with encrypted data to be assured of message authentication and non-repudiation.

This can archived by combining digital signatures with encryption scheme. Let us briefly discuss how to achieve this requirement. There are two possibilities, sign-then-encrypt and encrypt-then-sign….However, the crypto system based on sign-then-encrypt can be exploited by receiver to spoof identity of sender and sent that data to third party. Hence, this method is not preferred. The process of encrypt-then-sign is more reliable and widely adopted.

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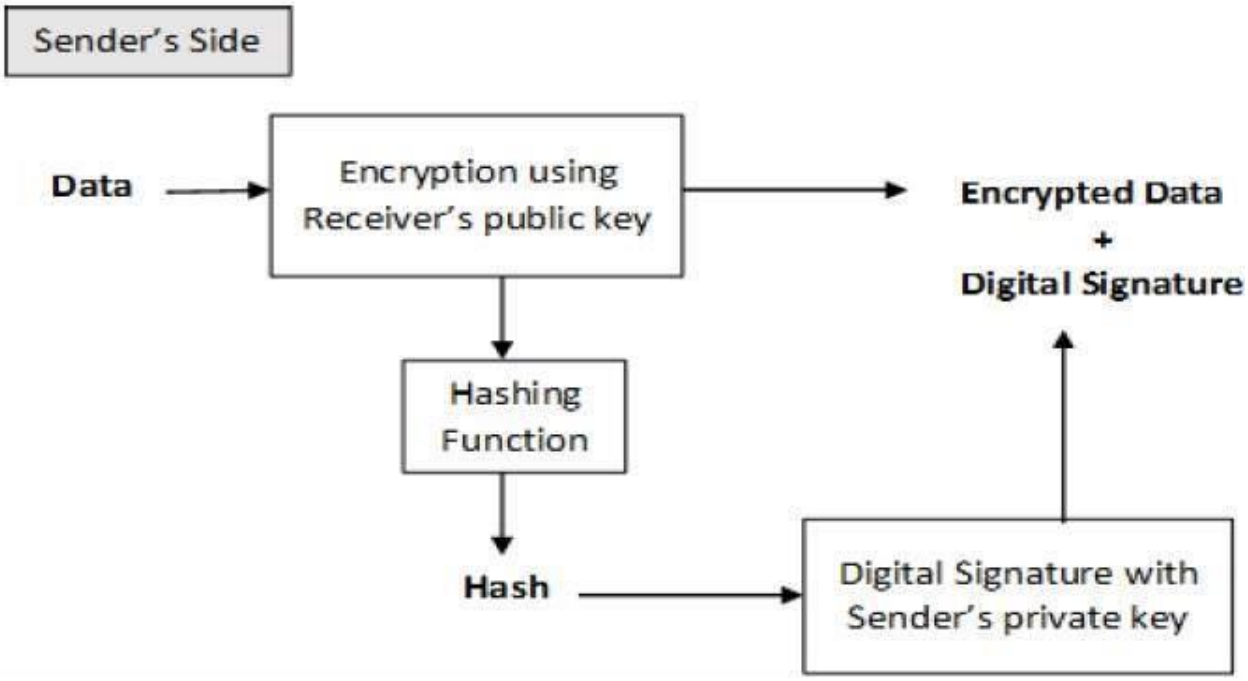
This is depicted in the following illustrations:-



The receiver after receiving the encrypted data and signature on it, first verifies the signature using sender's public key. After ensuring the validity of the signature, he then retrieves the data through decryption using his private key.

RSA for Digital Signatures

- For Alice to send a message to Bob,
- Alice encrypts m with her private key
- Alice encrypts with Bob's public key
- Bob decrypts with his private key
- Bob decrypts with Alice's public key
- $m=A(B'(B(A'(m)))$

Cryptography | One Time Password (OTP) algorithm

Authentication, :-the process of identifying and validating an individual is the rudimentary step before granting access to any protected service (such as a personal account). Authentication has been built into the cyber security standards and offers to prevent unauthorized access to safeguarded resources. Authentication mechanisms today create a double layer gateway prior to unlocking any protected information.

This double layer of security, termed as two factor authentication, creates a pathway that requires validation of credentials (username/email and password) followed by creation and validation of the **One Time Password (OTP)**. The OTP is a numeric code that is randomly and uniquely generated during each authentication event. This adds an additional layer of security, as the password generated is fresh set of digits each time an authentication is attempted and it offers the quality of being unpredictable for the next created session.

The two main methods for delivery of the OTP is:

1. SMS-Based:

This is quite straightforward. It is the standard procedure for delivering the OTP via a text message after regular authentication is successful. Here, the OTP is generated on the server side and delivered to the authenticator via text message. It is the most common method of OTP delivery that is encountered across services.

2. Application-Based:

This method of OTP generation is done on the user side using a specific smartphone application that scans a QR code on the screen. The application is responsible for the unique OTP digits. This reduces wait time for the OTP as well as reduces security risk as compared to the SMS based delivery.

The most common way for the generation of OTP defined by The Initiative For Open Authentication (OATH) is the **Time Based One Time Passwords (TOTP)**, which is a Time Synchronized OTP. In these OTP systems, time is the cardinal factor to generate the unique password.

The password generated is created using the current time and it also factors in a secret key. An example of this OTP generation is the Time Based OTP Algorithm (TOTP) described as follows:

- Backend server generates the secret key
- The server shares secret key with the service generating the OTP
- A hash based message authentication code (HMAC) is generated using the obtained secret key and time. This is done using the cryptographic SHA-1 algorithm.
- Since both the server and the device requesting the OTP, have access to time, which is obviously dynamic, it is taken as a parameter in the algorithm. Here, the Unix timestamp is considered which is independent of time zone i.e. time is calculated in seconds starting from January First 1970. Let us consider "0215a7d8c15b492e21116482b6d34fc4e1a9f6ba" as the generated string from the HMAC-SHA1 algorithm.

The code generated is 20 bytes long and is thus truncated to the desired length suitable for the user to enter. Here dynamic truncation is used. For the 20-byte code "0215a7d8c15b492e21116482b6d34fc4e1a9f6ba", each character occupies 4

bits.The entire string is taken as 20 individual one byte sting.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
12	15	a7	d8	c1	5b	49	2e	21	11	64	82	b6	d3	4f	c4	e1	a9	f6	ba

We look at the last character, here a. The decimal value of which is taken to determine the offset from which to begin truncation. Starting from the offset value, 10 the next 31 bits are read to obtain the string "6482b6d3″. The last thing left to do, is to take our hexadecimal numerical value, and convert it to decimal, which gives 1686288083.

All we need now are the last desired length of OTP digits of the obtained decimal string, zero-padded if necessary. This is easily accomplished by taking the decimal string, modulo 10 ^ number of digits required in OTP. We end up with "288083" as our TOTP code.

Next-A counter is used to keep track of the time elapsed and generate a new code after a set interval of time

Next-OTP generated is delivered to user by the methods described above.

Apart from the time-based method described above, there also exist certain mathematical algorithms for OTP generation for example a one-way function that creates a subsequent OTP from the previously created OTP.

The two factor authentication system is an effective strategy that exploits the authentication principles of "something that you know" and "something that you have".The dynamic nature of the latter principle implemented by the One Time Password Algorithm is crucial to security and offers an effective layer of protection against malicious attackers. The unpredictability of the OTP presents a hindrance in peeling off the layers that this method of cryptography has to offer.

Computer Network | Password authentication protocol (PAP):- There are simply two methods to authenticate PPP links namely Password Authentication Protocol (PAP) and Challenge Handshake Authentication Protocol (CHAP). From these two authentication protocols, PAP is less secured as the password is sent in clear text and is performed only at the initial link establishment.

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Password-Authentication-Protocol-(PAP) –

PAP is a password Authentication Protocol used by PPP links to validate users. PAP authentication requires the calling device to enter the username and password. If the credentials match with the local database of the called device or in the remote AAA database then it is allowed to access otherwise denied.

Features –

Some of the features of PAP are:

1. The password is sent in clear text.
2. All network operating system support PAP.
3. It uses two-way Handshake Protocol.
4. It is non-interactive.
5. PAP supports both one-way authentication (unidirectional) and two-way authentication (bidirectional).

Configuration –

PAP EXAMPLE

There is a small topology in which there are 2 routers namely R1 and R2. R1 having ip address 10.1.1.1/30 on s0/0 and R2 have ip address 10.1.1.2/30 on s0/0.

1)First, we will create local database on R1 by providing username and password:

R1(config)#username Router1 password GeeksforGeeks

2) Configuring local database on R2:

R2(config)#username Router2 password GeeksforGeeks

3) Remember, by default HDLC is configured on Cisco routers therefore first we have to change the encapsulation to PPP and enable PAP.

R2(config)# int s0/0

R2(config-if)#encapsulation ppp

R2(config-if)#ppp authentication pap

R2(config-if)#ppp pap sent-username Router1 password GeeksforGeeks

4) Enabling PAP on R2:

R2(config)# int s0/0

R2(config-if)#encapsulation ppp

R2(config-if)#ppp authentication pap

R2(config-if)#ppp pap sent-username Router1 password GeeksforGeeks

Here, notice that username and password are case-sensitive. Also, on router R1 we have to give a username and password.

Note –This command can also be used on the router which wants to authenticate (calling router) in case of one-way authentication i.e only calling router will authenticate.If two-way authentication, i.e both client and remote device are going to authenticate to each other, is operating then we have to make a local database and use this command on both devices.

In addition if we want to use CHAP first and PAP as backup when CHAP fails, we can configure it by the command.

```
R1(config)#int s0/0
R2(config-if)#ppp authentication chap pap
```

Also, if we want as CHAP as backup then use the command.

```
R1(config)#int s0/0
R2(config-if)#ppp authentication pap chap
```

When to use PAP –

PAP is usually used in following scenarios:

1. When the application doesn't support CHAP.
2. Circumstances where it is necessary to sent a plain text password to stimulate a login at the called device (remote host).
3. When there is occurrence of incompatibilities between different vendors of CHAP.

Advantage of CHAP over PAP –

Some of the advantages are:

1. CHAP is more secured than PAP.
2. CHAP can provide authentication periodically to recognise that the user accessing the PPP link is same or not.
3. In CHAP, the real passwords are never shared on the link instead a hash value of it is calculated and transferred.

Advantage of PAP over CHAP –

The only advantage PAP holds over CHAP is that it is supported by the all the network operating system vendors therefore it can be said that PAP is used where CHAP is not supported. But if CHAP is supported then it is recommended to use CHAP as it is more secured…..

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