EBU6010

Cryptography and Cyber Security

Block 4

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Review

- **Services: Authentication Applications**
  - Kerberos
- **Certificates (Key Authentication)**
  - X.509
- **IP Security (IPSec)**
  - IPSec proper (authentication and encryption)
  - IPSec key management
- **Firewalls**

This week..

- Web Security (TLS/SSL)
- Email Security (PGP, S/MIME,..)
- Threats to Security
- Course Summary & Revision

Web Security

TLS/SSL

The Web

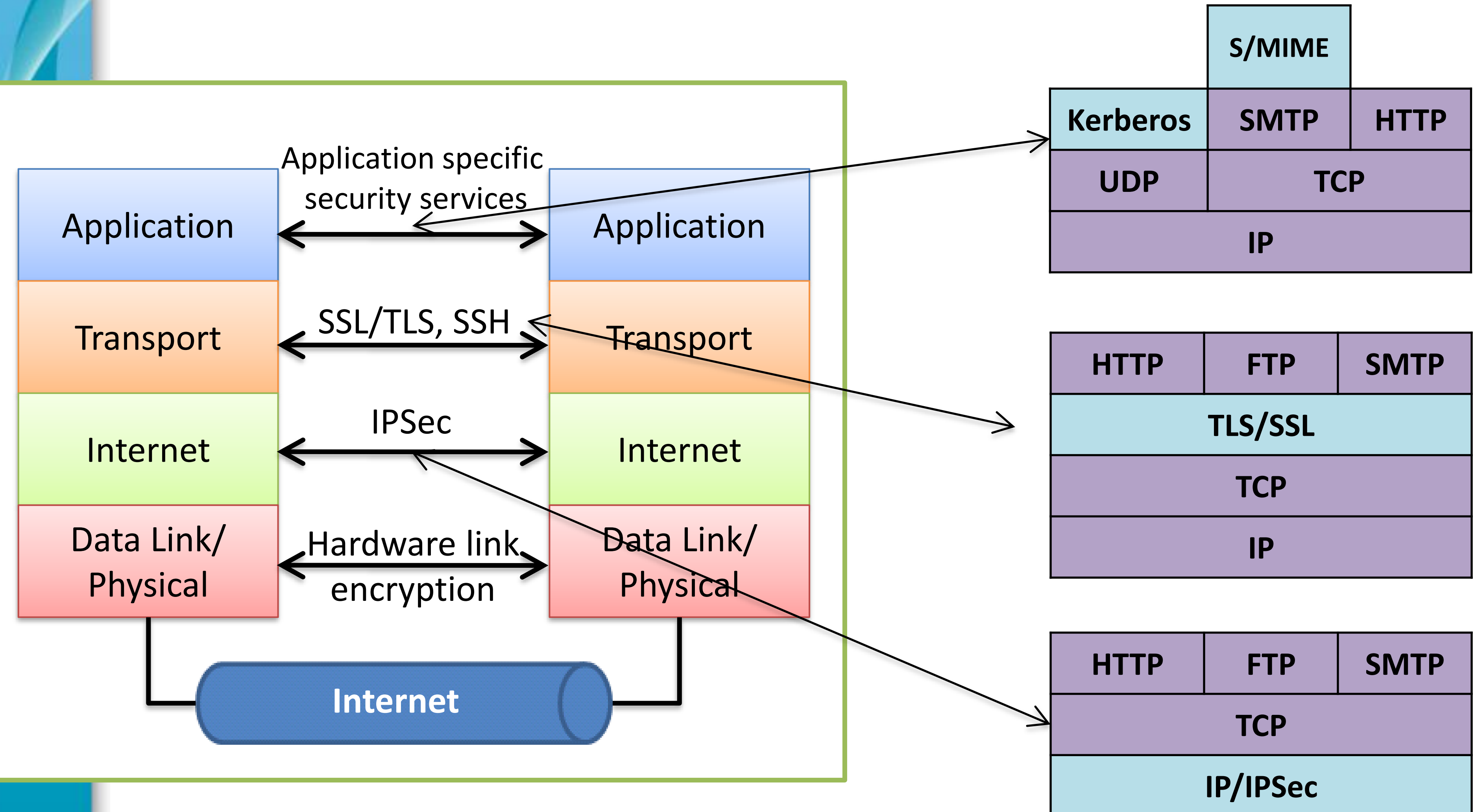
Did we trust early web developments for E-commerce applications?

- **Is a client/server application running over the Internet using TCP/IP**
  - Web browsers are easy to use and configure, but the underlying software is complex. This complexity may hide potential security flaws.
  - A Web server can be exploited as a launching pad into the corporation's entire computer system.
  - In general users are not aware of security risk or do not have the know-how to take effective countermeasures.

Threats

	Threats
Integrity	Modification of user data/memory/message traffic in transit, Trojan horse browser.
Confidentiality	Eavesdropping, theft of info/data, info about network configuration or identity of client/server.
Denial of Service	Killing user threads, flooding with bogus threats, filling up disk/memory, Isolating machine by DNS attacks
Authentication	Impersonation of legitimate users, data forgery

Web Traffic: Security Services



Transport Layer Security (TLS)

derived from Secure Sockets Layer (SSL)

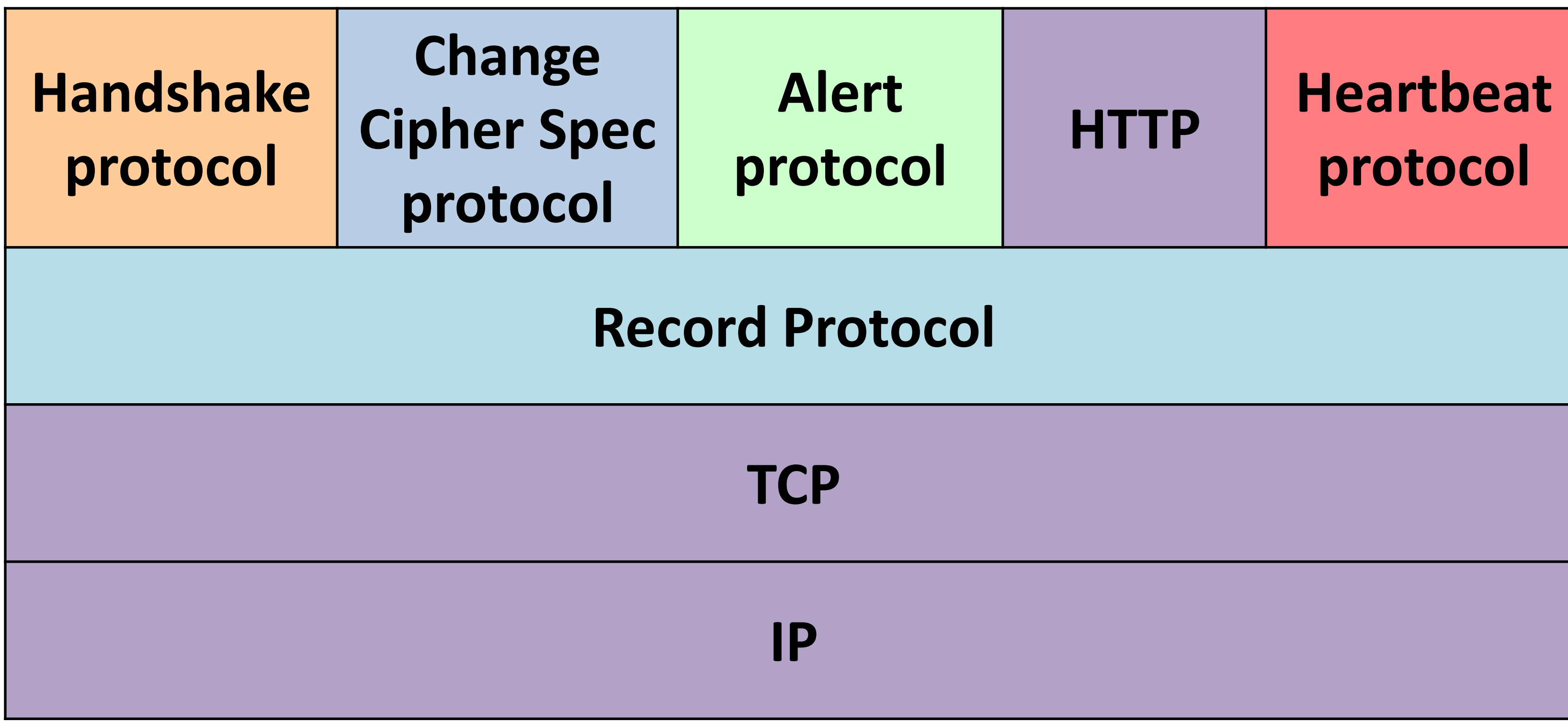
History of SSL & TLS

- SSL was first developed by Netscape the mid-1990s.
- The IETF released protocol versions *TLS 1.0* in 1999, *TLS 1.1* in 2006, and *TLS 1.2* in 2008. The latest version, which is significantly different, is *TLS 1.3*.
- TLS runs over the *Transmission Control Protocol* (TCP).

- All SSL versions are *deprecated* now (SSL 3.0 was prohibited in June 2015), however SSL may still appear in documents.

TLS Architecture

- Two layers of protocols



TLS Architecture

- Handshake Protocol
- Record Protocol
- Change Cipher Spec Protocol
- Alert Protocol
- Heartbeat protocol

TLS Connection

- A **connection** in TLS is a transport that provides suitable type of service (they are peer-to-peer and transient). Every connection is associated with one session.
- A connection state is defined by the following parameters:
  - Server and client random (i.e. nonce)
  - Server write MAC secret
  - Client write MAC secret
  - Server write key
  - Client write key
  - Initialisation vectors (i.e. IVs for CBC encryption)
  - Sequence number

TLS Session

- A **session** in TLS is an association between a client and a server.
- Sessions are created by the Handshake Protocol.
- Sessions define a set of cryptographic security parameters, which can be shared among multiple connections.
- Sessions are used to avoid expensive renegotiation of security parameters for each connection.

A TLS Session state is defined by:

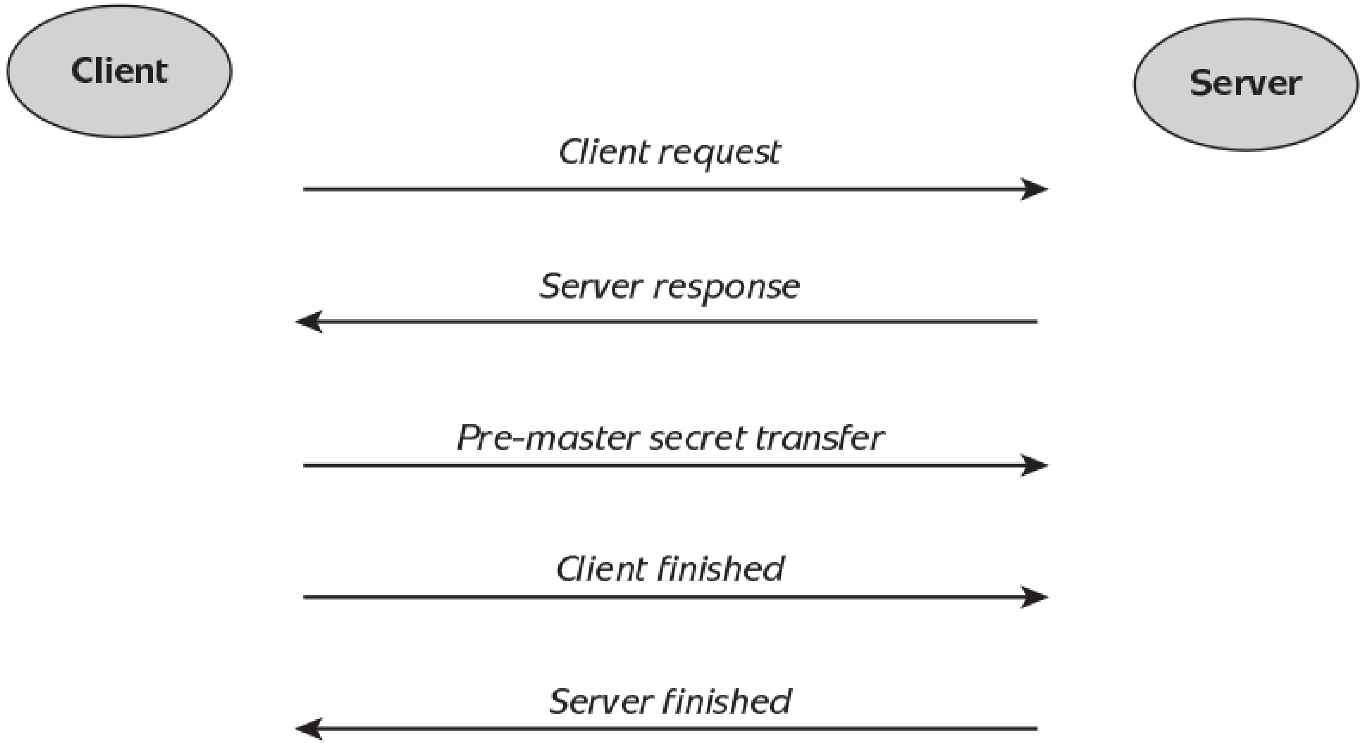
- Session identifier
- Peer certificate (X509.v3) – authentication; to create trust
- Compression method
- Cipher Spec (null, DES, MD5, SHA-1, …)
- Master secret – to authenticate (& relate) the connection to a session
- Is resumable – a flag indicating whether the session can be used to initiate new connections

Handshake protocol

- This protocol performs all the tasks requiring agreement between the two entities before they set up the secure TLS channel:
  - agree on the *cipher suite* to be used to establish the secure channel;
  - allows the server and client to authenticate each other; and
  - establish the keys needed to secure the channel.

- *Cipher suite*: a list that contains the combinations of cryptographic algorithms.

Handshake protocol (A simple version for TLS 1.2 and earlier versions)

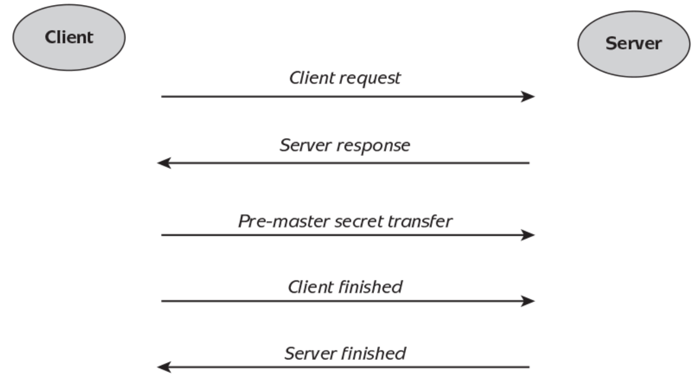


- ***Client Request***:
  - a *session ID*: a unique identifier for the session;
  - a pseudorandom number (nonce) r_C: for the provision of freshness; and
  - a list of cipher suites the client supports (including *key exchange* method)

Supported Key exchange methods

- ***RSA***
- ***Fixed Diffie-Hellman***: Diffie-Hellman public parameters contained in server's certificate, signed by CA.
- ***Ephemeral Diffie-Hellman***:
  - Sender generates a fresh set of parameters, and sends the public values alongside a digital signature on the chosen parameters.
  - This creates ephemeral(temporary, one-time) secret keys, and considered the most secure DH option.
  - Offers perfect *forward secrecy*.
- ***Anonymous Diffie-Hellman***: Basic Diffie-Hellman used without authentication.

Handshake protocol (A simple version for TLS 1.2 and earlier versions)

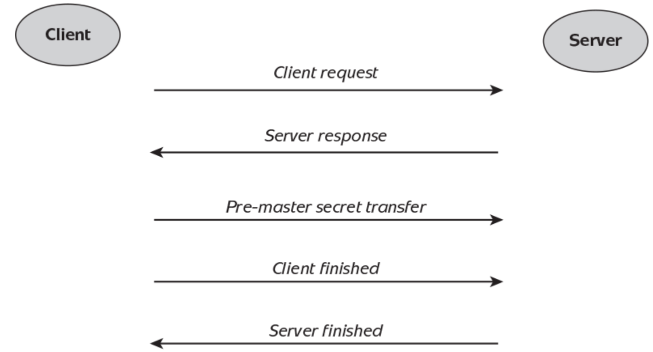


Server Response:

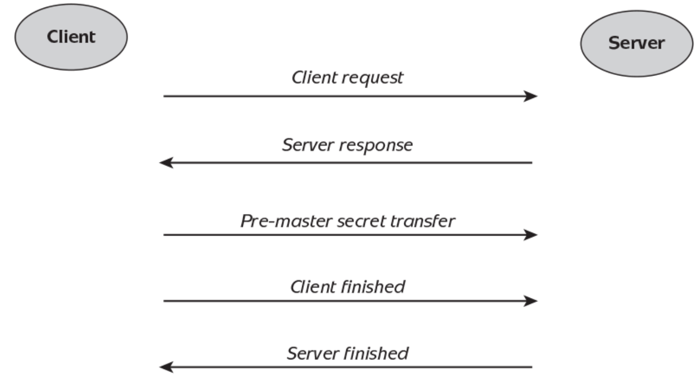
- the session ID;
- Server's nonce r_S;
- the particular cipher suite the server has decided to use;
- a copy of the server's public-key certificate; and
- if the Ephemeral Diffie–Hellman is chosen, then the server also generates a fresh set of parameters, and sends the public values alongside a digital signature on the chosen parameters.

After receiving server response message, *client* need to

- check the server's public-key certificate is valid
- If the Ephemeral Diffie–Hellman protocol is being used, then the client should verify the digital signature on the Diffie–Hellman parameters.



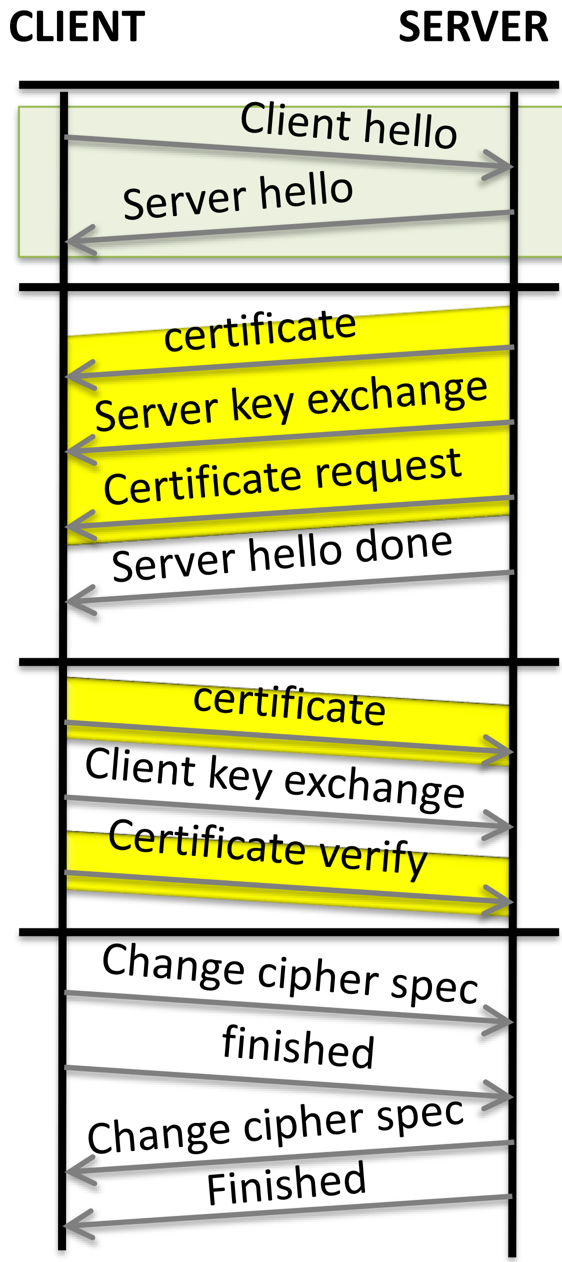
- ***Pre-master Secret Transfer***: The client and server now need to agree on a shared secret K_P (the *pre-master secret)*.
  - **RSA**: the client generates K_P, encrypted using the server's public key and sends to the server;
  - **Ephemeral Diffie–Hellman**: the client generates a fresh temporary Diffie–Hellman key pair and sends the public value to the server, after which both client and server compute the shared secret K_P.
- The client and server can now derive the keys required to secure the TLS session:
  - compute the *master secret* K_M using a key derivation function, taking K_P, r_C and r_S as part of inputs.
  - derive MAC and encryption keys from K_M. From this point on, all exchanged messages are cryptographically protected.



- ***Client Finished***.
  - The client computes a MAC on the hash of all the messages sent thus far.
  - This MAC is then encrypted and sent to the server.

- ***Server Finished***.
  - The server checks the MAC received from the client.
  - The server then computes a MAC on the hash of all the messages sent thus far.
  - This MAC is then encrypted and sent to the client.

Handshake Protocol: Phase 1

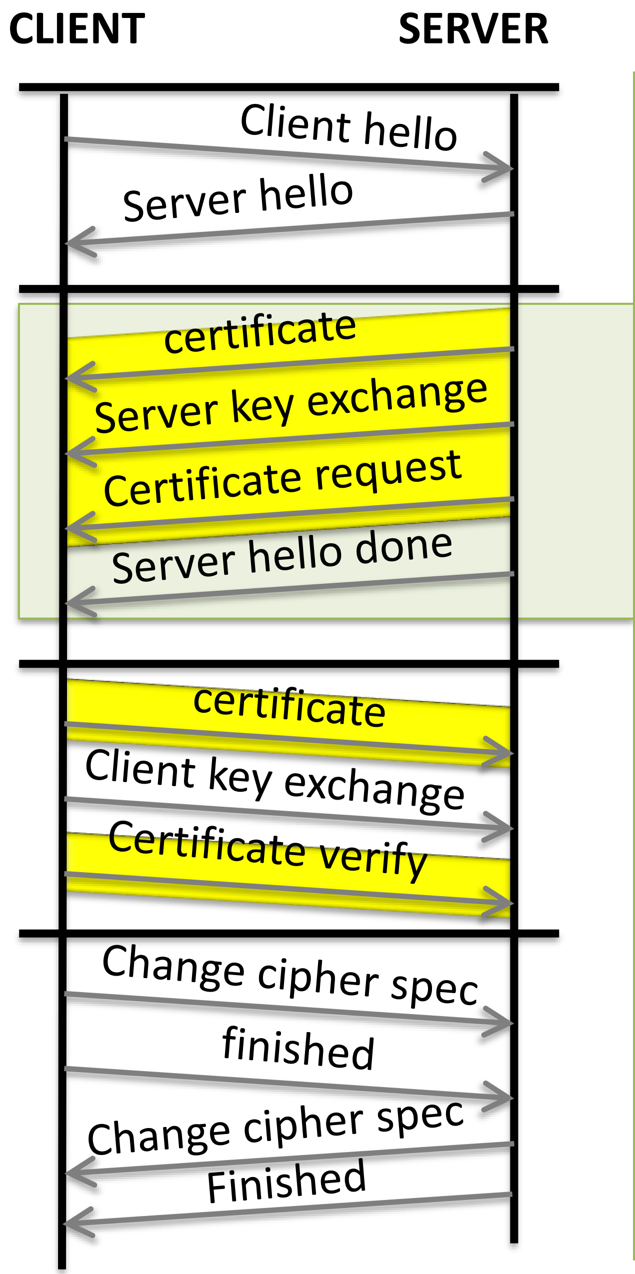


Establish Security Capabilities

Client hello = <u>Version</u> (The highest TLS version understood by the client),
<u>Nonce</u>,
<u>Session ID</u>,
<u>Compression method</u>
<u>Cipher Suite</u>
Key Exchange
RSA
Fixed Diffie-Hellman
Ephemeral Diffie-Hellman
Anonymous Diffie-Hellman
CipherSpec
Cipher Algorithm (RC4,3DES, AES..)
*MAC algorithm (SHA)
*Cipher Type (block, stream)
*IsExportable
*Hash size
*Key Material (data used in generating write keys)
*IV size

Server hello = replies choosing from the client list a set of algorithms and parameters.

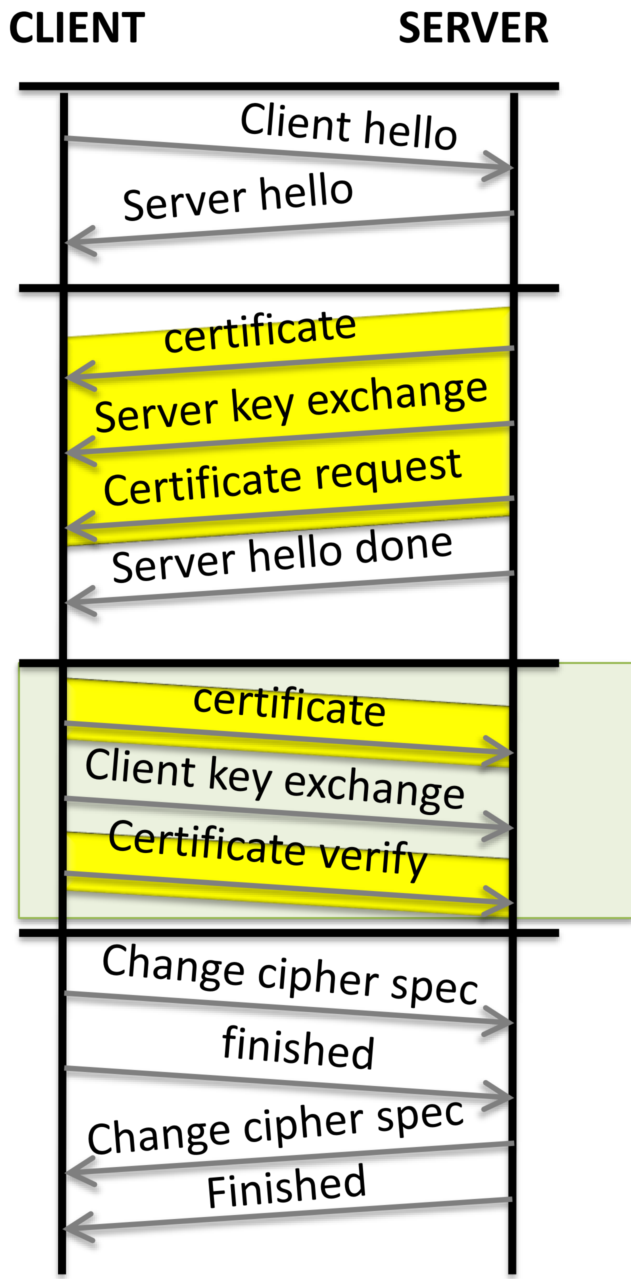
Handshake Protocol: phase 2



Authentication and Key exchange

Certificate	Contains Server's certificate (X.509)
Server key exchange	Needed if • Anonymous Diffie-Hellman • Ephemeral Diffie-Hellman • RSA key exchange (Signature only RSA key)
Certificate request	Server requests a certificate from client (optional) • Certificate type • Certificate authority
Server hello done	Indicate the end of Serve Hello and associated messages

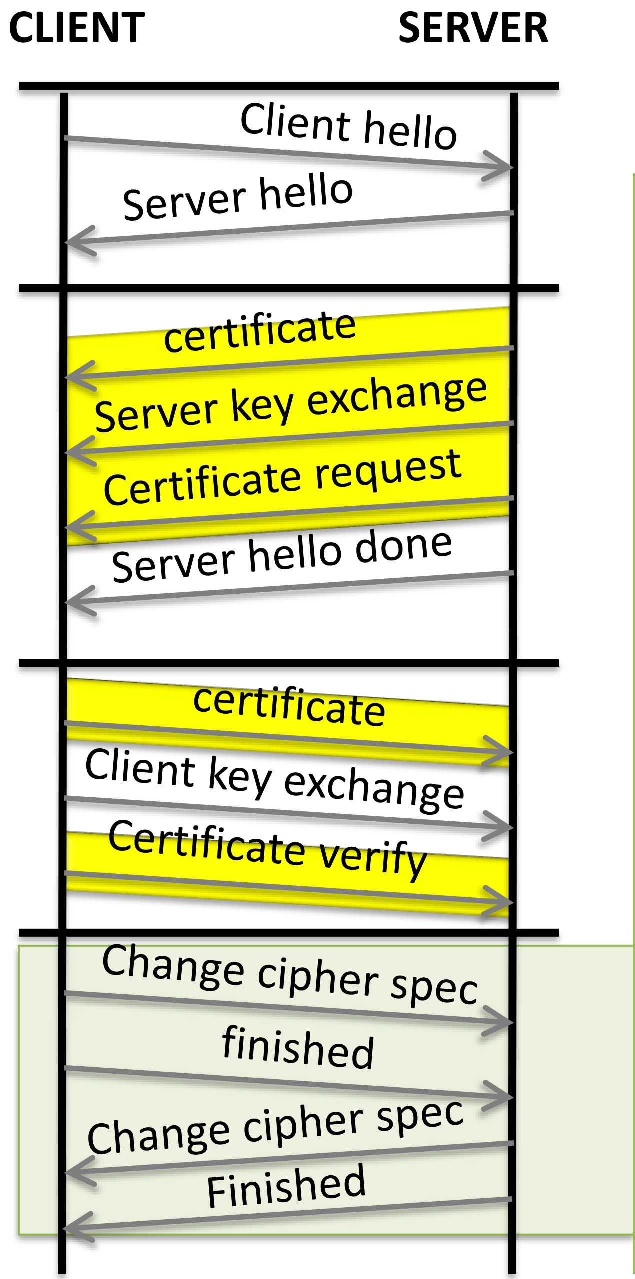
Handshake Protocol: phase 3



Client Authentication and Key exchange

Certificate message	Send the requested certificate
Client key exchange	Depending on the key exchange mechanism • RSA • Diffie-Hellman (ephemeral and Anonymous) • Fixed Diffie-Hellman
Certificate verify	Verification of clients certificate

Handshake Protocol: phase 4



Finish (Change Cipher Spec)

Change cipher spec (Client)	Copies the pending CipherSpec into the current CipherSpec
Finished	Verifies the key exchange and authentication processes to be successful
Change cipher spec (Server)	Copies the pending CipherSpec into the current CipherSpec
Finished	Verifies the key exchange and authentication processes to be successful

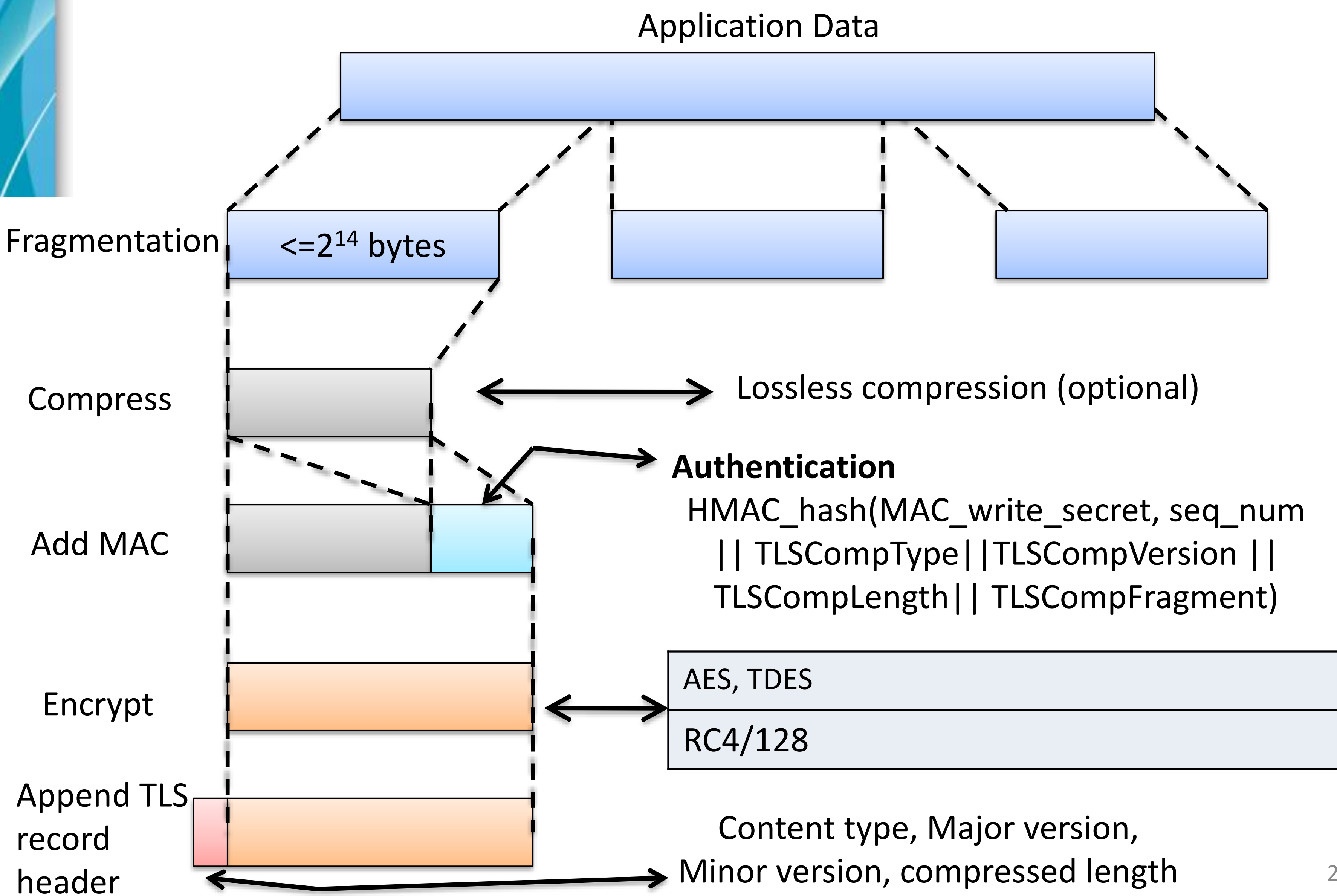
Change Cipher Spec Protocol

- This is essentially the last phase of Handshake protocol.
- Change of cipher suites
  - Sends one message which updates the cipher suite to be used on this connection. The message is a single byte with value 1.

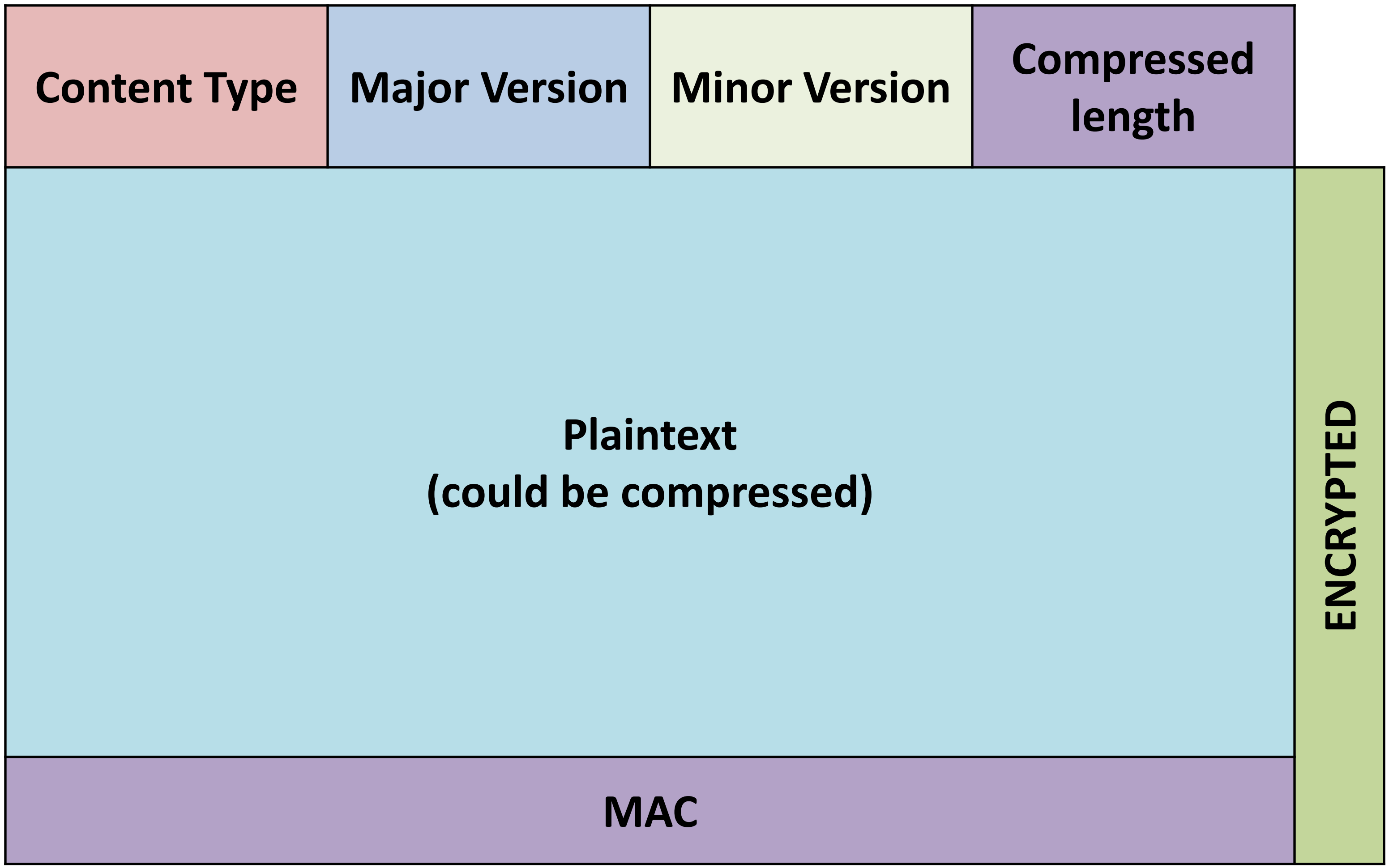
TLS Record Protocol

- TLS Record protocol provides:
  - Confidentiality
  - Message Integrity

TLS Record Protocol



TLS Record Format



Alert Protocol

- Used to convey TLS-related alerts to the peer entity.
- Consist of two bytes, the first byte flags a
  - Warning or
  - Fatal
- The second byte contains the code that indicates the specific alert, e.g.
    - bad_record_mac
    - handshake_failure
    - decryption_failed
    - bad_certificate; etc

Heartbeat protocol

- A **heartbeat** is a periodic signal generated to indicate normal operation or to synchronise.
- A heartbeat protocol is typically used to monitor the availability of a protocol entity. (In the specific case of TLS, a heartbeat protocol was defined in 2012 in RFC6250.)
- Two purposes:
  1. assures the sender that the recipient is still alive, even though there may not be any activity for a while.
  2. avoid closure by a firewall that does not tolerate idle connections.

TLS attacks

- Attacks on the handshake protocol
- Attacks on the record and application data protocols
  - chosen-plaintext attack, session hijacking
- Attacks on the PKI
- Other attacks
  - Heartbleed (buffer over-read)

TLS 1.3

- Various attacks on earlier versions of TLS resulted in a series of fixes having to be proposed, which is not desirable.
- The Handshake Protocol is somewhat inefficient.
- Major revision of TLS resulted in TLS 1.3 published in August 2018 (RFC8446).
- What is new in TLS 1.3**:**
  - **Perfect Forward Secrecy**. removing support for key establishment based on RSA and mandating the use of Ephemeral Diffie–Hellman.
  - **New Handshake Protocol**. only requiring one full round trip between client and server. More of the data exchanged in the new Handshake Protocol is encrypted.
  - **Authenticated encryption modes**. Encryption in TLS 1.3 must be conducted using an authenticated-encryption mode of a block cipher.

Email Security

Email Security

- Basic requirements
  - Confidentiality
  - Authentication
  - Integrity

- Other requirements
  - Non-repudiation
  - Proof of submission
  - Proof of delivery
  - Anonymity
  - Revocability
  - Resistance to traffic analysis

PGP Learning outcome

- Understand and be able to explain:
  - The purpose of PGP
  - The services provided by PGP
  - Details of authentication and confidentiality service provided by PGP
- Understand:
  - The compression and compatibility service of PGP

Pretty Good Privacy (PGP)

- Largely the effort of one person, Phil Zimmerman. Released in 1991 and distributed worldwide via Usenet post.
  - Uses the best available cryptographic algorithms.
  - Easy-to-use and platform independent.
  - PGP is free (even the source), easy to get and it is documented.
  - Wide range of applicability, from corporations to individuals.
  - Is not controlled by any governmental or standards organisation.
  - Currently OpenPGP is defined in RFC 4880.

PGP

Actual operations of PGP consist of **five services**:

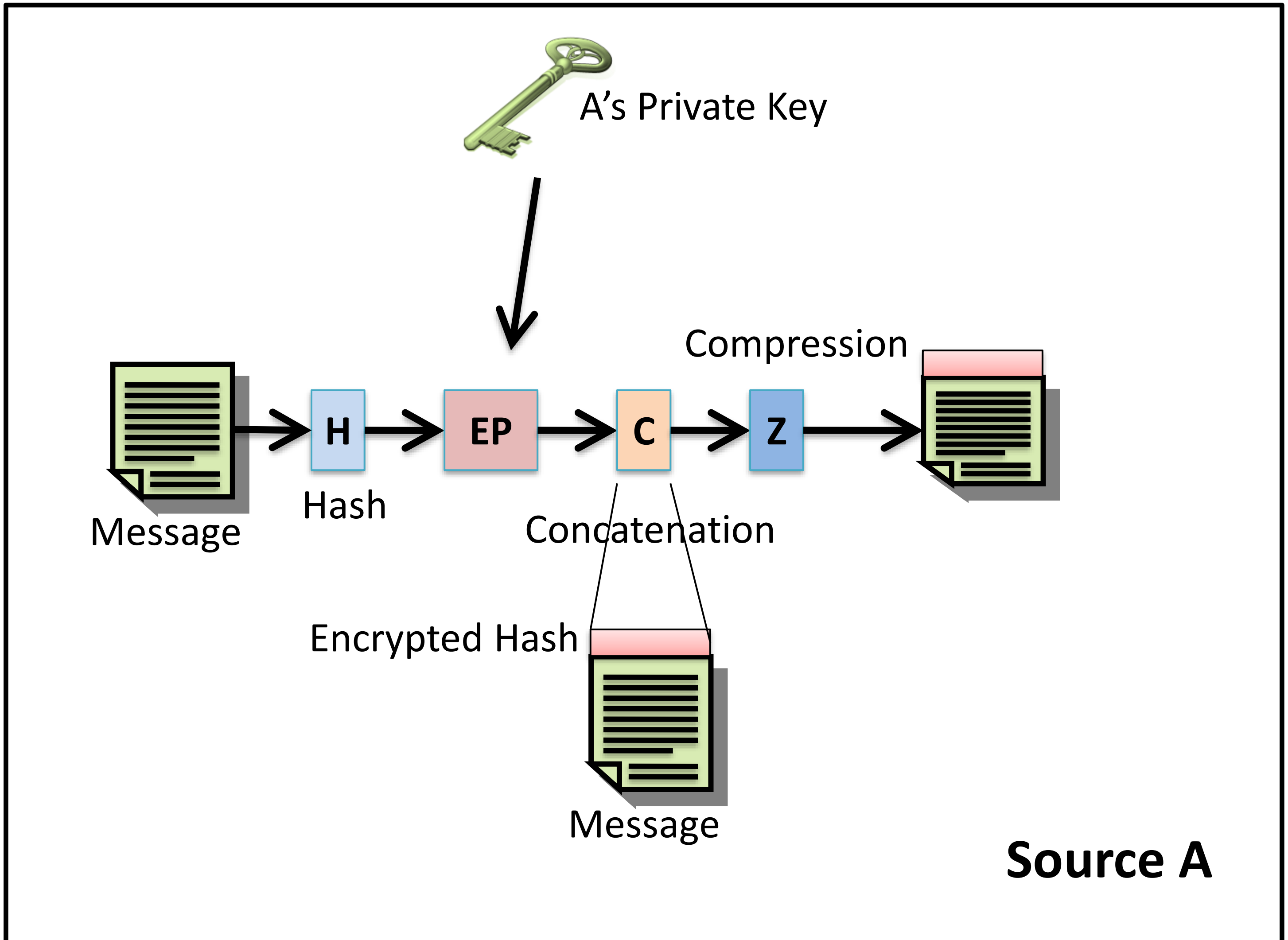
- **Authentication** - DSS/SHA or RSA/SHA
- **Confidentiality** – CAST5 or IDEA or RSA or 3DES
- **Compression**: A message may be compressed, for storage or transmission using ZIP
- **E-mail compatibility**: To provide transparency for e-mail applications, an encrypted message may be converted to an ASCII using Radix-64
- **Segmentation**: To accommodate maximum message size limitations, PGP performs segmentation and reassembly.

PGP

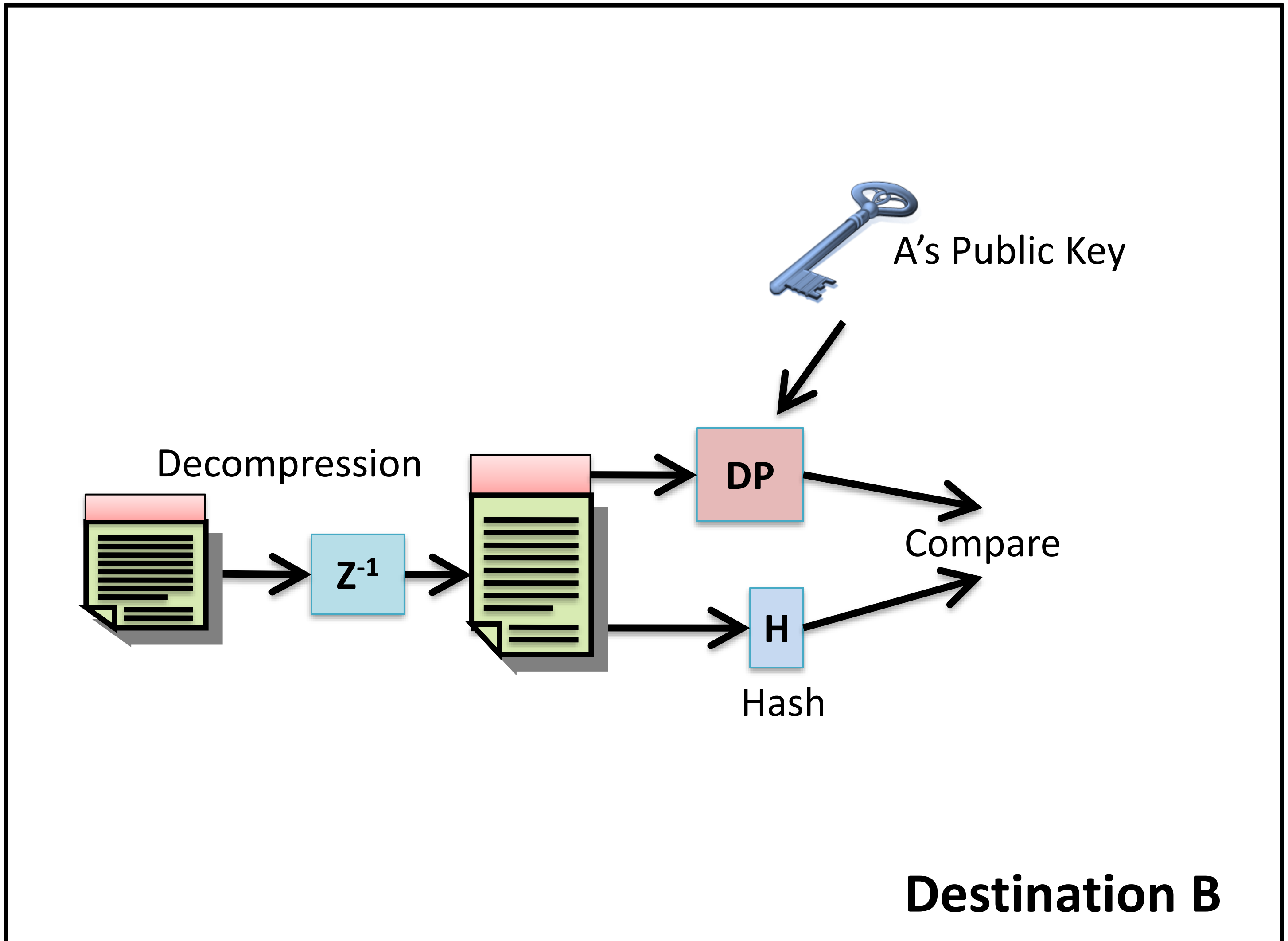
- The latest PGP services

Function	Algorithm
Digital Signature	DSS/SHA or RSA/SHA
Message Encryption	CAST5 or IDEA Triple DES. With Diffie-Hellman or RSA for key exchange
Compression	ZIP
e-mail compatibility	Radix-64
Segmentation	-

Authentication



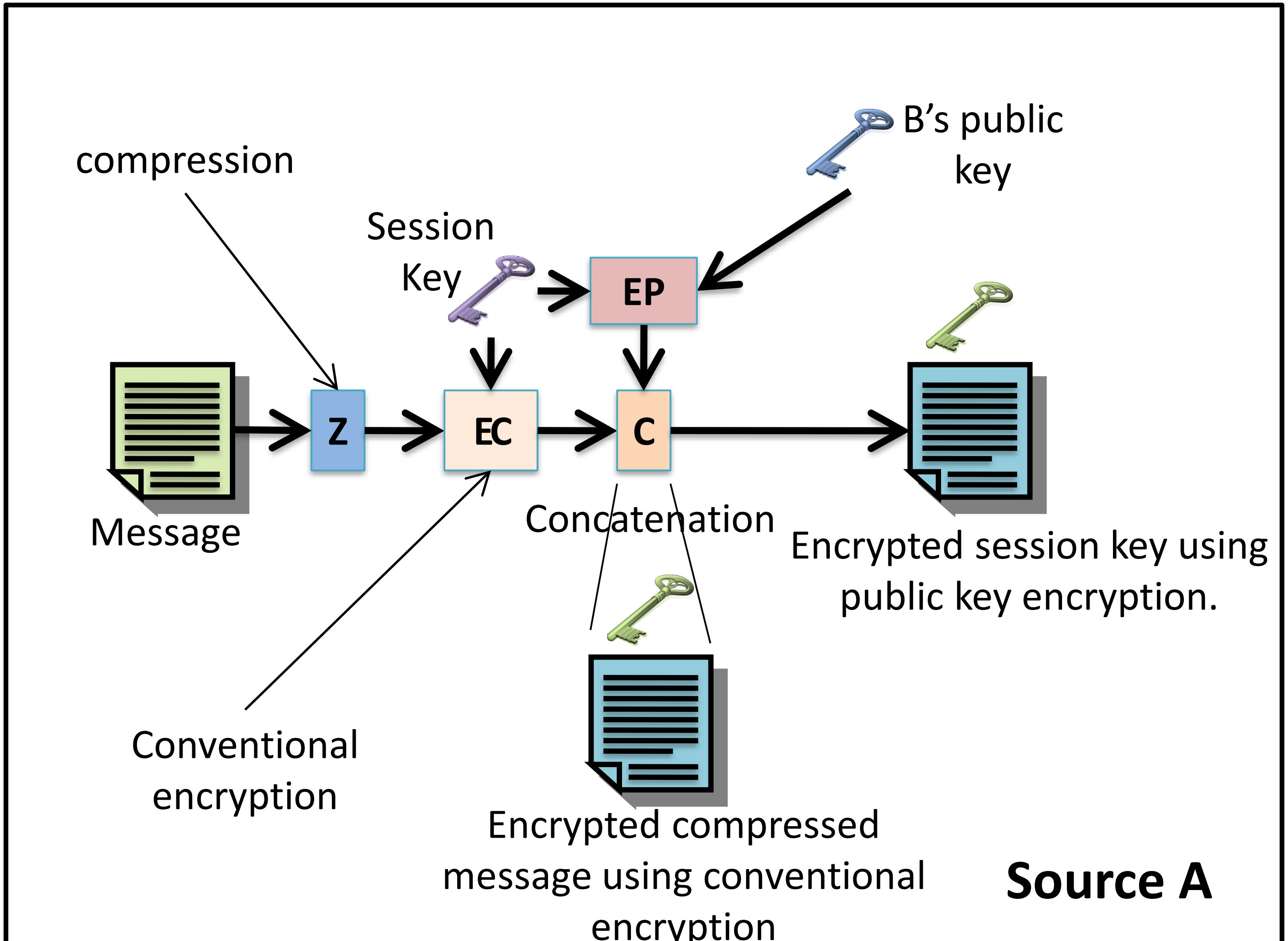
Authentication



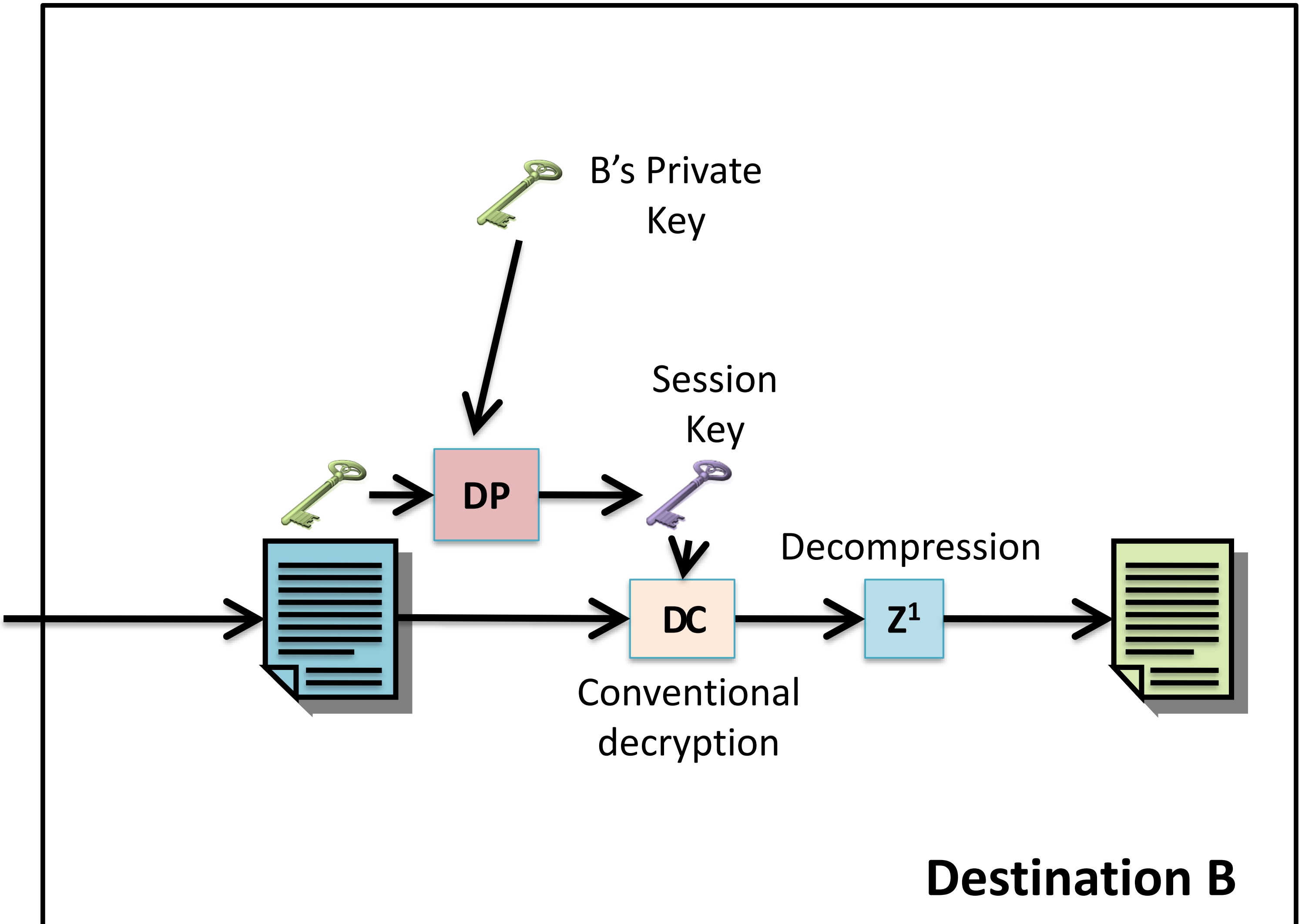
Authentication

- Create a message.
- SHA used to generate 160-bit hash code.
- Hash encrypted with RSA using sender’s private key, the result is prepended to the message.
- The receiver uses RSA with sender’s public key.
- The receiver decrypts the hash with the sender’s public key.
- The receiver generates a new hash code from the received message and compares it with the decrypted hash to prove authenticity.

Confidentiality



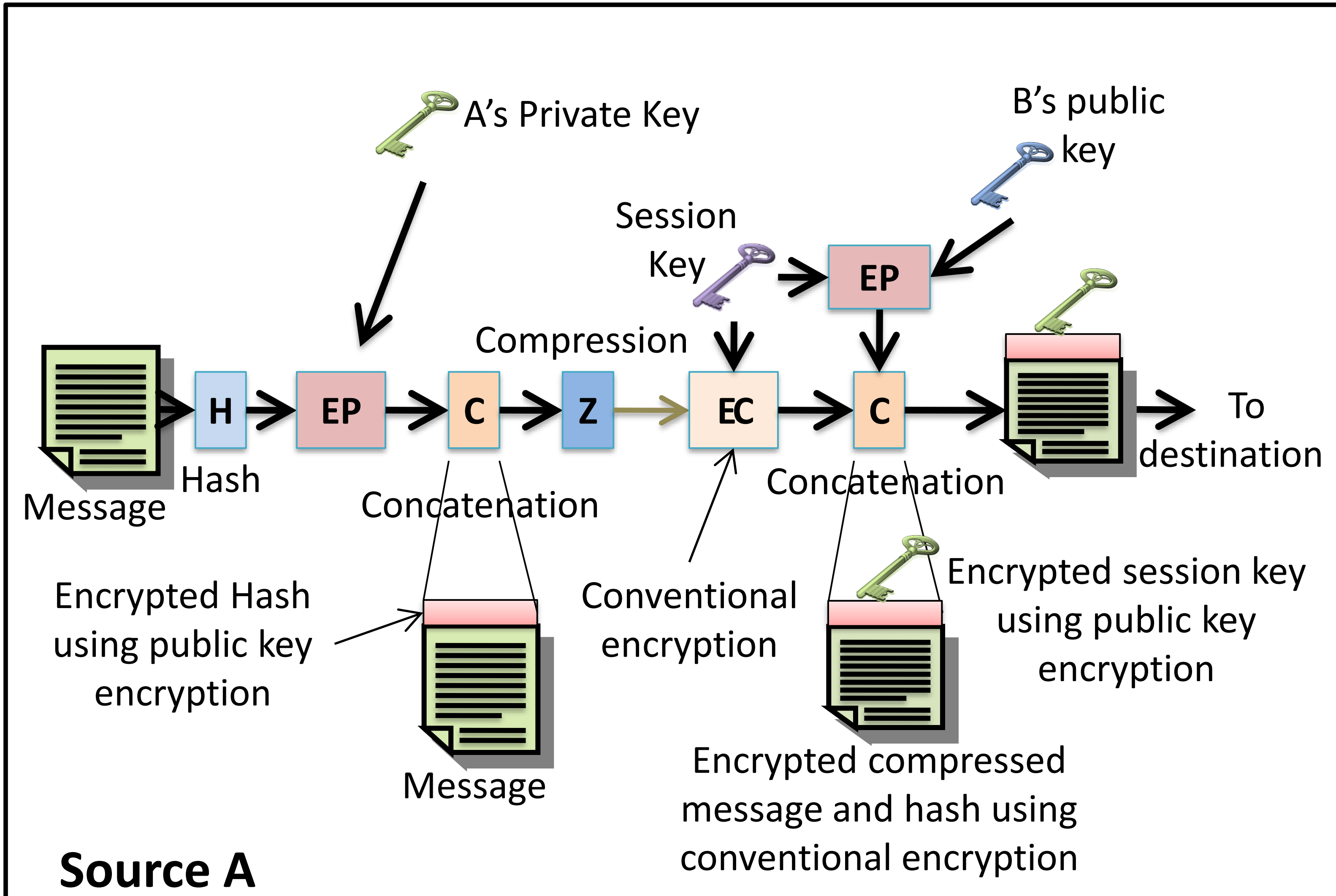
Confidentiality



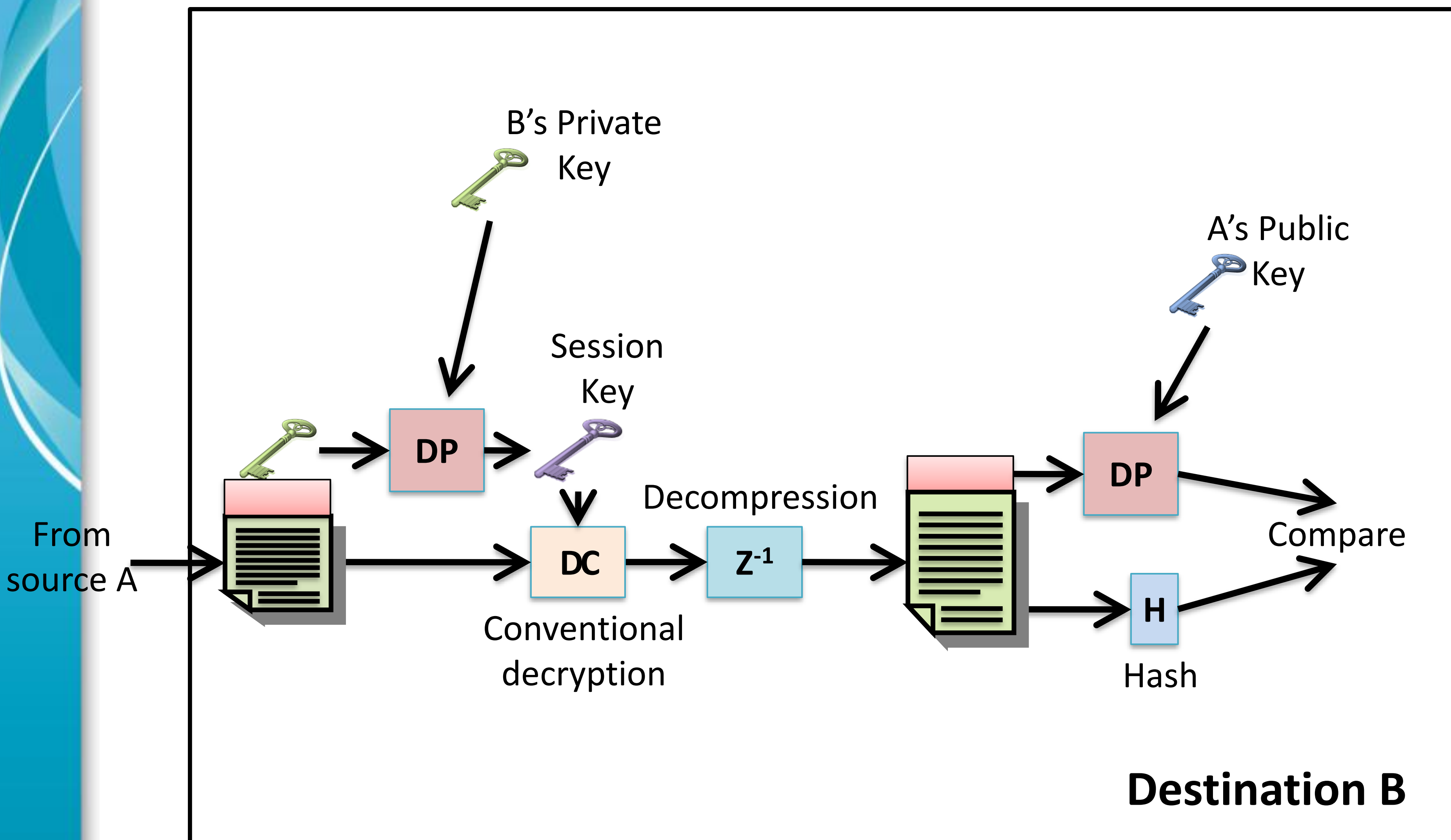
Confidentiality

- Sender generates a message.
- Sender generates a session key (128-bits long).
- Message is encrypted using CAST5 (or IDEA, 3DES) using the session key.
- The session key is encrypted using RSA and the recipient’s public key. The encrypted session key is prepend to the message.
- The receiver uses RSA and its’ private key to recover the session key.
- Using the session key, the receiver decrypts the message.

Authentication & Confidentiality



Confidentiality & Authentication



Compression

To save space both for e-mail and storage as a default PGP compresses the message **after** applying the signature but **before** encryption.

- If the message was first compressed and then signed then for future verification
  - A compressed version of the document has to be stored, or
  - Re-compress the message when verification is required.

Compression

- But more relevantly, a compression algorithm is **not** deterministic.
  - That is the same message when compressed can produce different compressed forms (this depends on running speed vs compression ratio).
  - If sender and receiver use different settings for the compression algorithm they obtain different forms. This makes authentication difficult.

- The compressed message has less redundancy so is more difficult to cryptanalysis.

E-mail compatibility

- When PGP transmits a message at least part of the message is encrypted. The encrypted part (can be the whole document) consist of a stream of 8-bit octets.

- Many electronic mail systems only permit the use of blocks consisting of ASCII text.

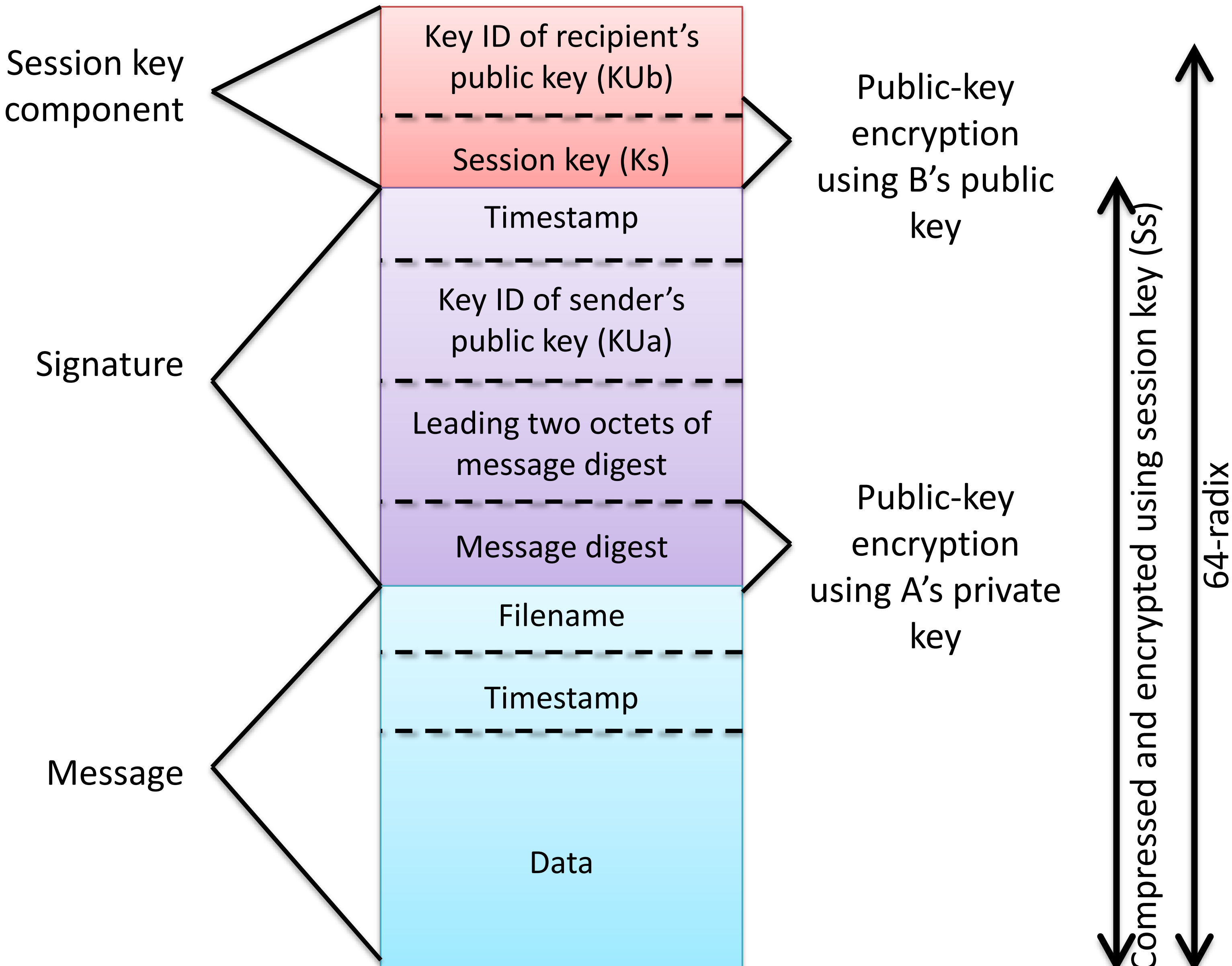
- PGP converts the raw 8-bit octets stream to a stream of printable ASCII characters using radix-64 expansion.

Radix-64 algorithm
- Maps 3 bytes to 4 printable chars
- Also appends a CRC to detect transmission errors

- PGP also segments messages if too big.

From A to B

General Format



PGP keys

- There are four types of keys
  - Pass-phrase key
  - Session keys (random keys generated)
  - Public-key
  - Private-key

- PGP allows to have more than one set of private-public keys per user.

Key management

- Because of the possibility of multiple public–private keys per user, the recipient of the message needs to know which of his/hers public key was used for encryption.
- One possibility is that the sender of the message includes the public key of the recipient, but it is unnecessarily wasteful of space.
- PGP send an identifier of the recipients public key.
- PGP assigns an ID to each public key by using the least significant 64 bits of the key. (ID $\rightarrow$ KU_A mod(2^64))

Key rings

- One or more keys stored together constitute a key-ring.
- There are two classes:
  - **Private-key ring:** Stores the private/public key pairs owned at this node.
  - **Public-key ring:** Stores the public keys of other users known at this node.

Key rings

Using Passphrase key

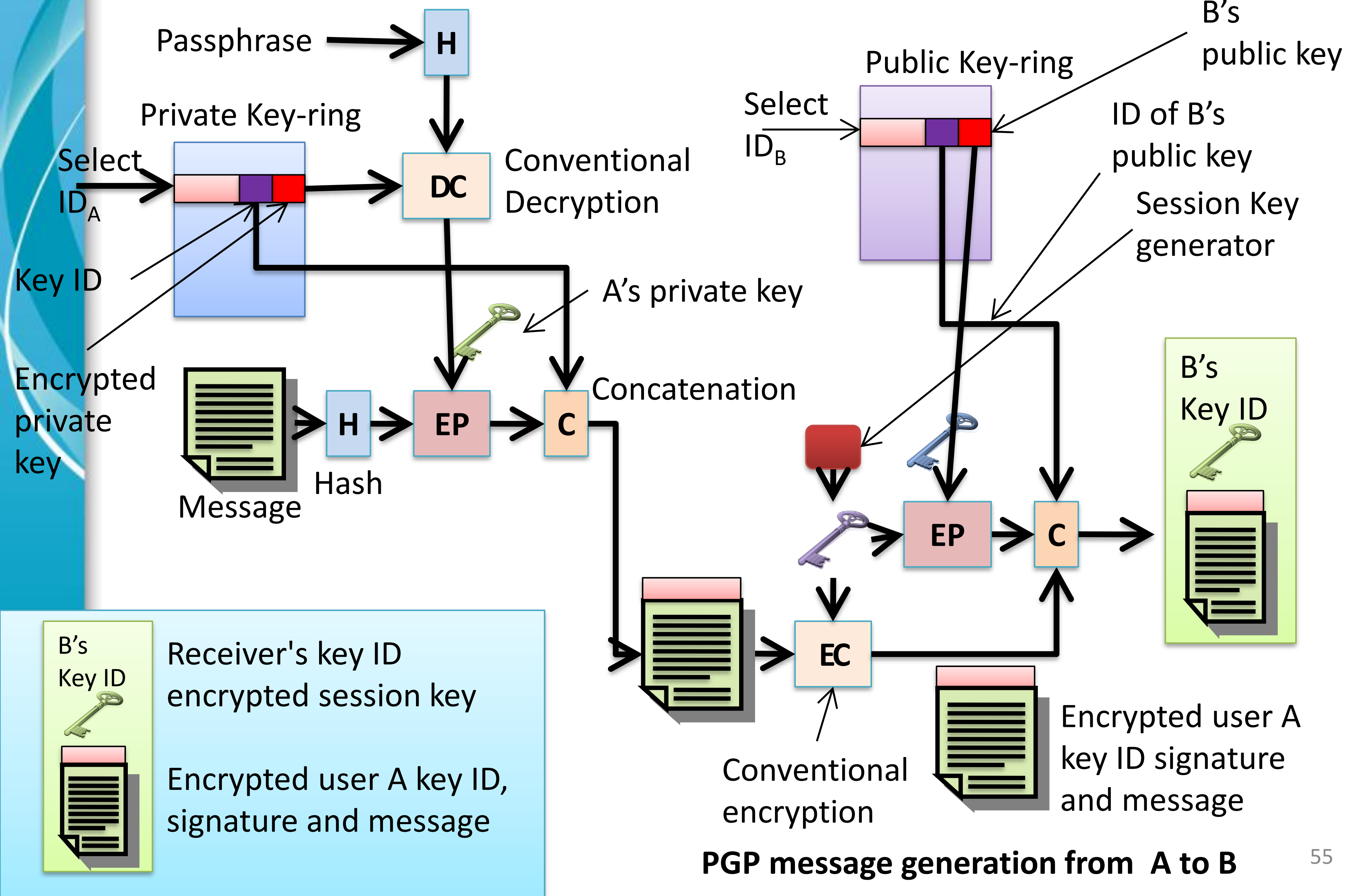
Private Key ring

Timestamp	Key ID	Public Key	Encrypted private key	User ID

Public Key ring

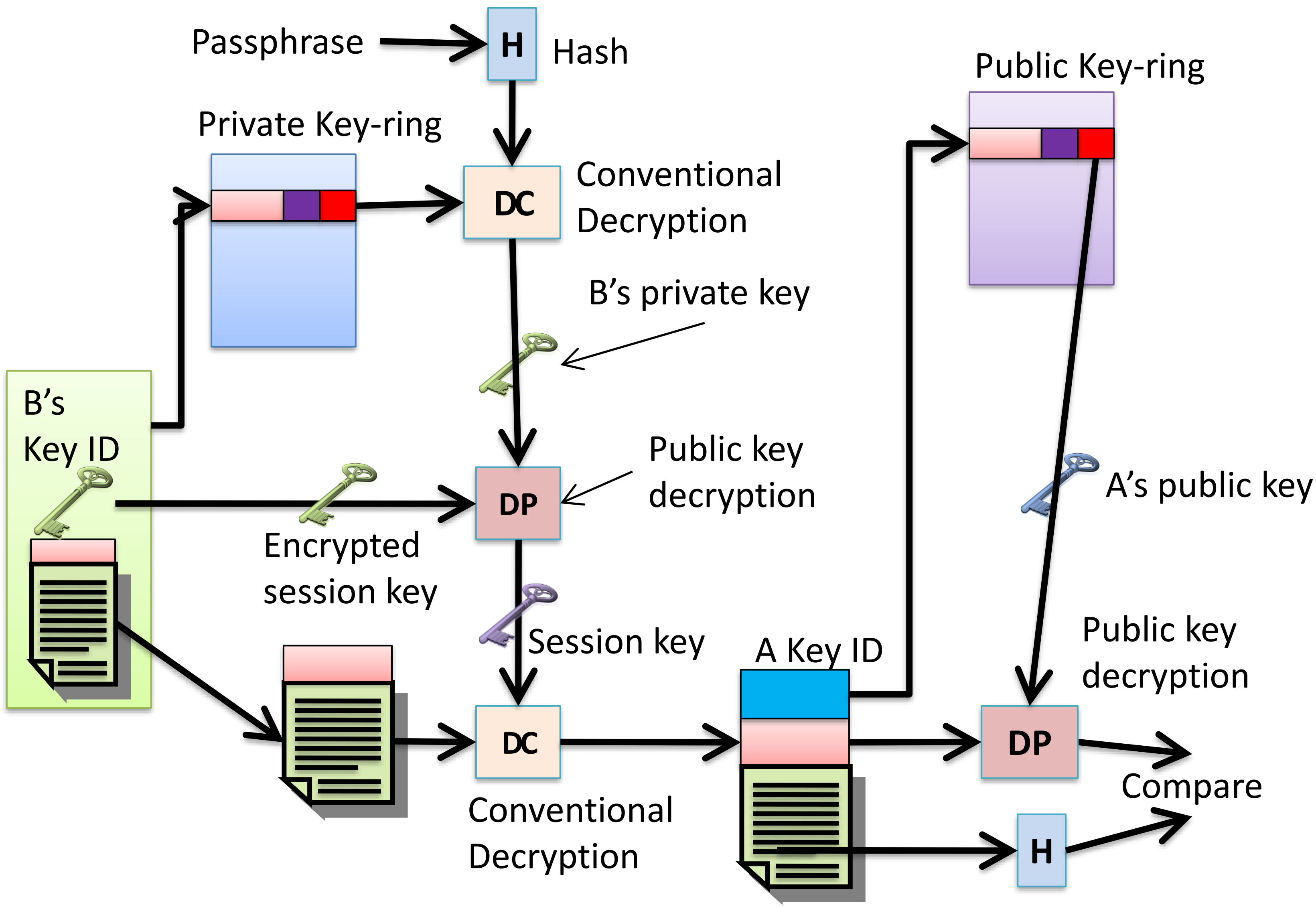
Timestamp	Key ID	Public Key	Owner Trust	User ID	Key legitimacy	Signature	Signature Trust

PGP message generation



PGP message generation from A to B

PGP message reception



PGP message reception from A to B

PGP Public-key management

- The problem: A's public-key ring contains a public key attributed to B, but how can A be sure the public key is from B, not someone else?
- The solution:
  - PGP does not include any specification for establishing certifying authorities
  - adopts a different trust model – the "web of trust"
  - Individuals sign one another's public keys (the "signature field" in the public-key ring) and create an interconnected community of public-key users.
  - PGP computes a *trust level* for each public key in key ring

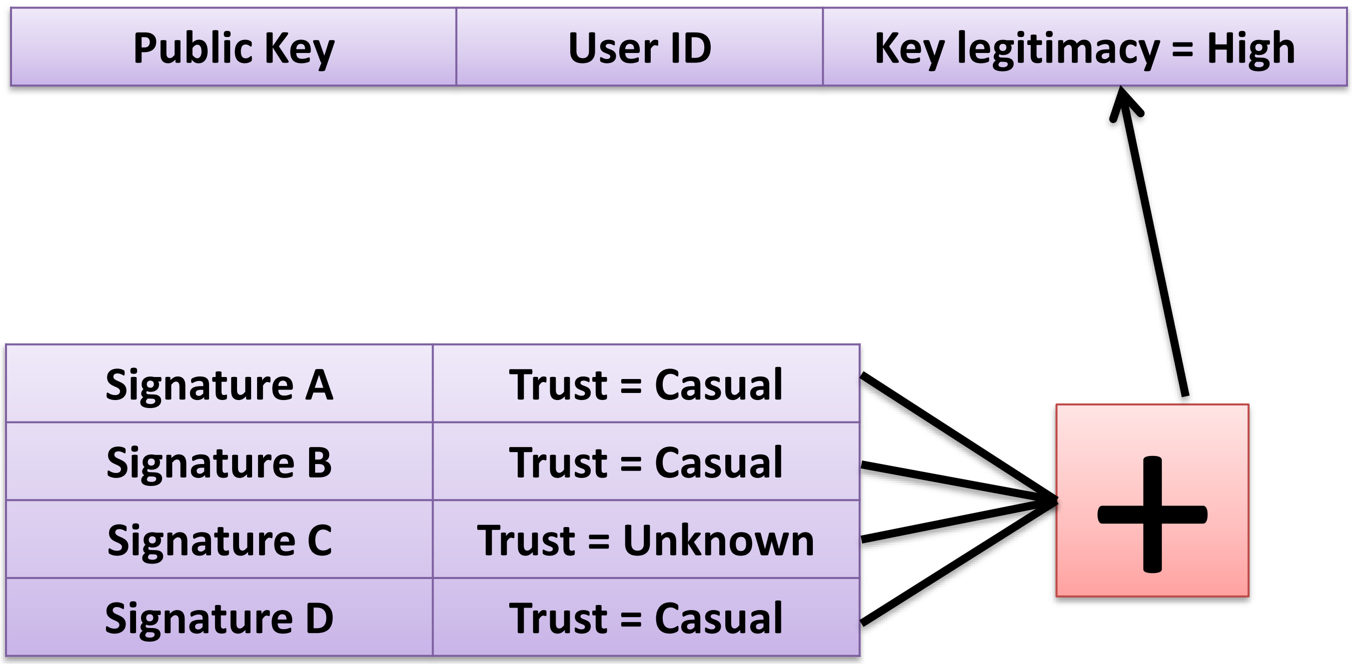
Trust

Timestamp	Key ID	Public Key	Owner Trust	User ID	Key legitimacy	Signature	Signature Trust

- **Key legitimacy** → indicates the extent to which PGP will trust that this is a valid public key for this user; the higher the level of trust, the stronger is the binding of this user ID to this key. This field is computed by PGP.
- **Owner Trust** → indicates the degree to which this public key is trusted to sign other public-key certificates; this level of trust is assigned by the user
- **Signature Trust** → indicates the degree to which this PGP user trusts the signer to certify public keys. The key legitimacy field is derived from the collection of signature trust fields in the entry.
- Example

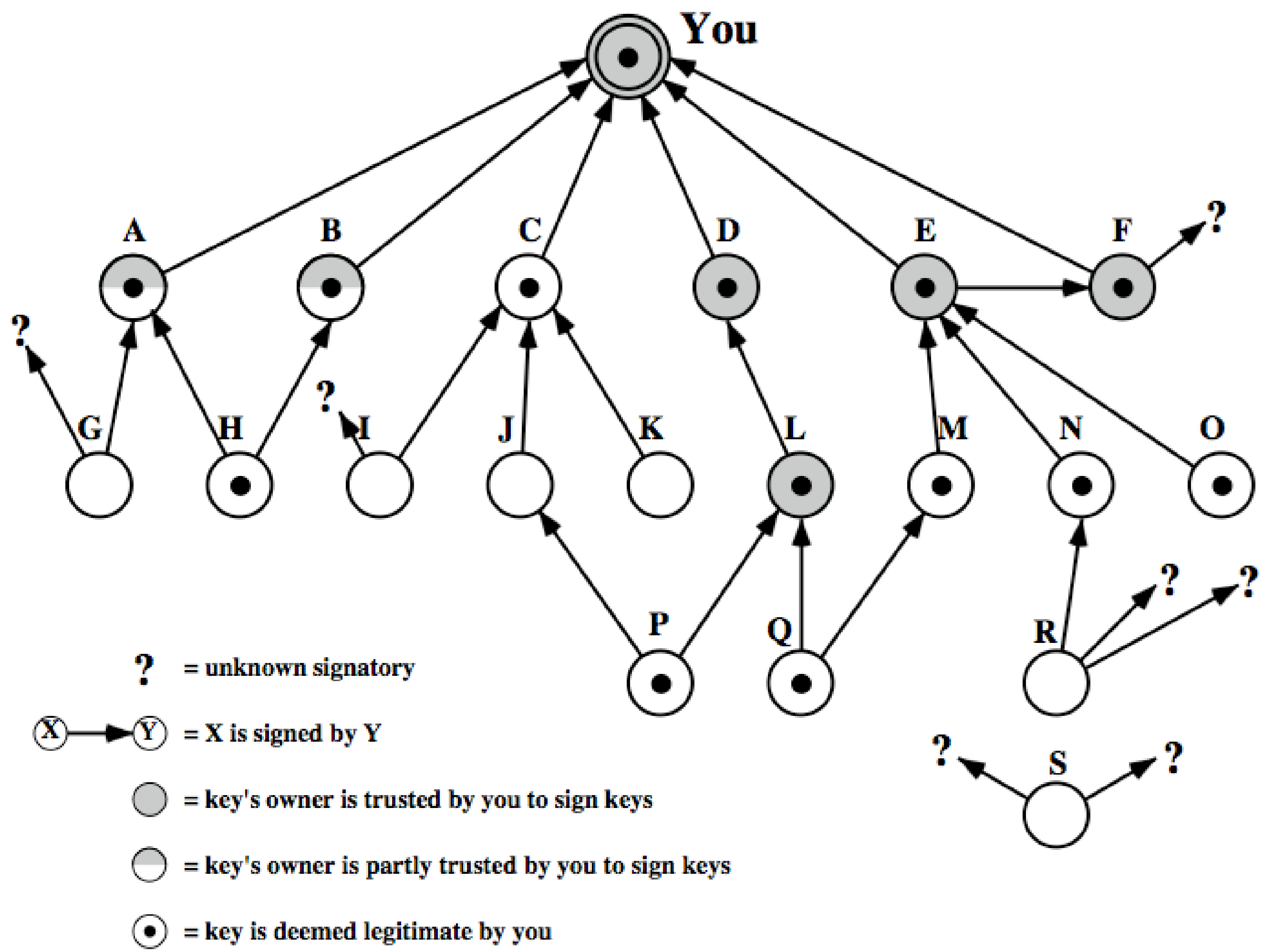
  UserID = politician
  - Owner Trust = low
  - Key legitimacy = high

Example of how PGP compute key legitimacy



PGP Trust Model Example

The structure of a public-key ring where the user has acquired a number of public keys, some directly from their owners and some from a third party such as a key server.



S/MIME Secure/Multipurpose Internet Mail Extension

- S/MIME is a security enhancement for the MIME Internet e–mail format standard based on technology from RSA Data Security.
- MIME provides a convenient mechanism for transferring composite data.
- Binary data handled via base64 encoding.
- S/MIME: security related information sent as sections of a multipart message
  - multipart/signed
  - multipart/encrypted

RFC5322

- Defines a format for **text** messages that are sent using electronic mail
- A message consists of header lines (the header) followed by unrestricted text (the body).
- This is an example message:

```
Date: October 8, 2009 2:15:49 PM EDT
From: “William Stallings” <ws@shore.net>
Subject: The Syntax in RFC 5322
To: Smith@Other-host.com
Cc: Jones@Yet-Another-Host.com

Hello. This section begins the actual
message body, which is delimited from the
message heading by a blank line.
```

Multipurpose Internet Mail Extensions (MIME)

- MIME is an extension to the RFC5322 framework
- MIME addresses some problems and limitations of the use of SMTP(Simple Mail Transfer Protocol) and RFC5322, e.g., cannot transmit executable files or other binary objects.
- The MIME specification includes the following elements:
  - Five new message header fields are defined (The **Content-Type** header field is used for secure communications)
  - A number of content formats are defined, which support multimedia electronic mail

MIME formats

- This is an example of **multipart type** email. The headers of a simple email in MIME looks like this (Taken from RFC 2046):

```
Date: Wed 09 Dec 2009 10:37:17 (GMT)
From: Nathaniel Borenstein <nsb@bellcore.com>
To: Ned Freed <ned@innosoft.com>
Subject: Sample message
MIME-version: 1.0
Content-type: multipart/mixed; boundary=“simple boundary”
This is the preamble. It is to be ignored, though it is
   handy place for email composers to include an
   explanatory note to non-MIME conformant readers.
-simple boundary
This is implicitly typed plan ASCII text. It does NOT end
   with a line break.
-simple boundary
Content-type: text/plain; charset=us-ascii
This is explicitly typed plain ASCII text. It DOES end
   with line break.
-simple boundary-
This is the epilogue. It is also to be ignored.
```

Secure/Multipurpose Internet Mail Extension (S/MIME)

- A security enhancement to the MIME Internet e-mail format standard based on technology from RSA Data Security

Summary of S/MIME services

Function	Typical Algorithm
Digital signature	RSA/SHA-256
Message encryption	AES-128 with CBC
Compression	unspecified
E-mail compatibility	Radix-64 conversion

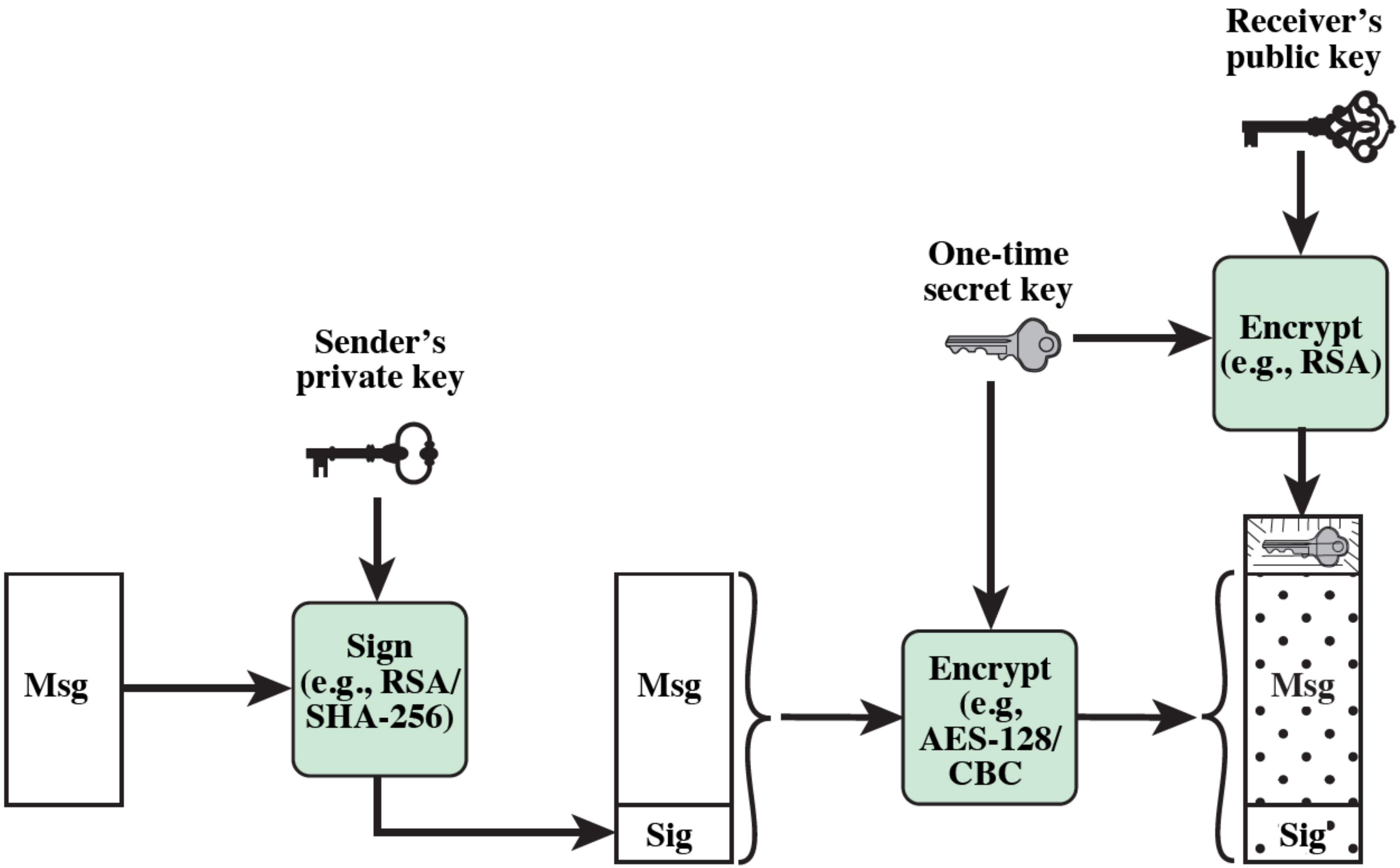
S/MIME Authentication

1. The sender creates a message
2. SHA-256 is used to generate a 256-bit message digest of the message
3. The message digest is encrypted with RSA using the sender's private key, and the result is appended to the message. Also appended is identifying information for the signer, which will enable the receiver to retrieve the signer's public key
4. The receiver then verifies the message digest.

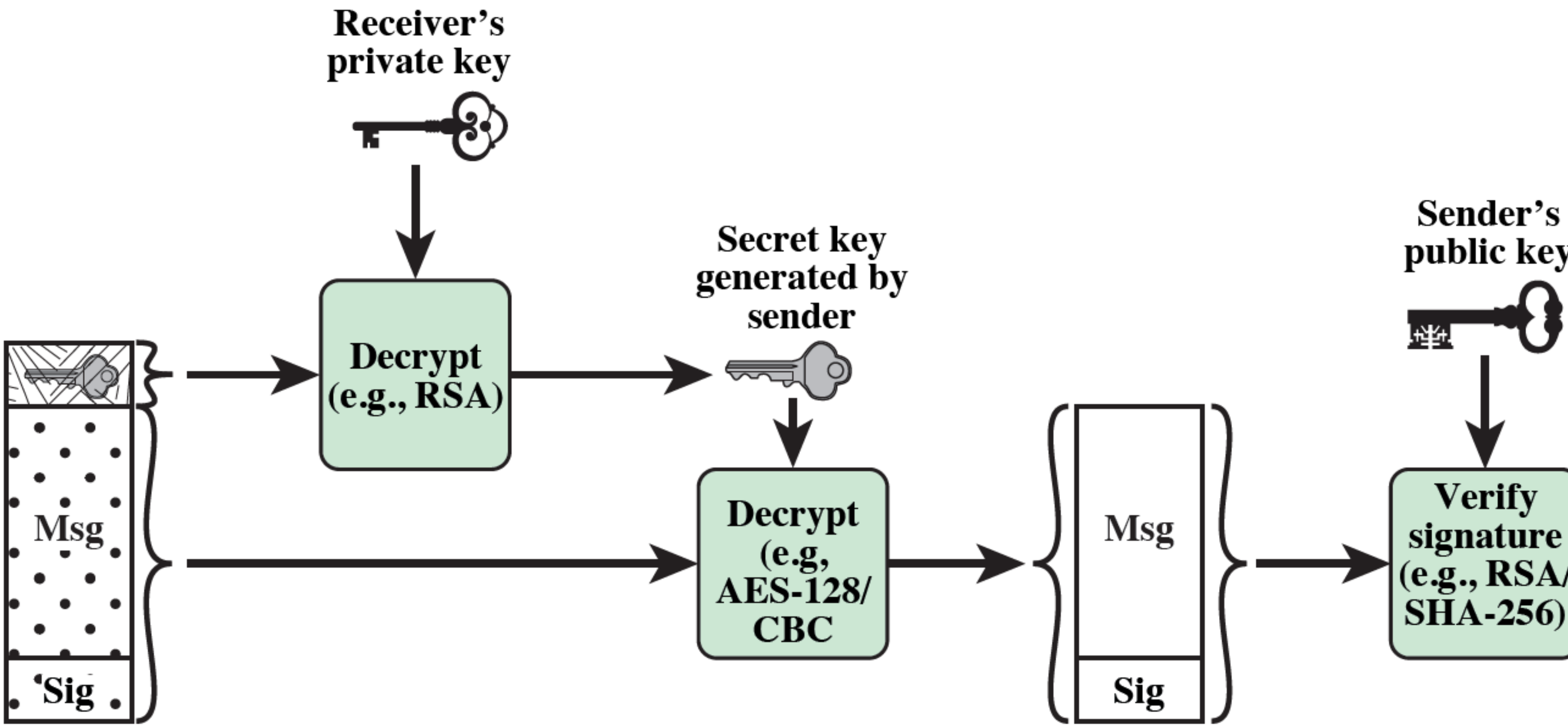
S/MIME Confidentiality

1. The sender generates a message and a random 128-bit number to be used as a content-encryption key for this message only.
2. The message is encrypted using the content-encryption key.
3. The content-encryption key is encrypted with RSA using the recipient's public key and is attached to the message.
4. The receiver uses RSA with its private key to decrypt and recover the content-encryption key.
5. The content-encryption key is used to decrypt the message.

Confidentiality and Authentication



Confidentiality and Authentication



S/MIME Cryptographic Algorithms

Function	Requirement
Create a message digest to be used in formatting a digital signature	• **MUST** support SHA-256. •**SHOULD** support SHA-1 • Receiver **SHOULD** support MD5 for backward compatibility.
Encrypt message digest to form digital signature	•**MUST** support RSA with SHA-256. •**SHOULD** support: DSA with SHA-256, RSASSA-PSS with SHA256, RSA with SHA-1, DSA with SHA-1, RSA with MD5
Encrypt session key for transmission with message	•**MUST** support RSA encryption (key size 512-1024 bits). •**SHOULD** support RSAES-OAEP, Diffie-Hellman ephemeral-static mode.
Encrypt message for transmission with a one-time session key	•**MUST** support AES-128 with CBC. •**SHOULD** support AES-192 CBC and AES-256 CBC, Triple DES CBC.

S/MIME Certificates processing

- Uses public-key certificates that conform to X.509 v3.
- Key management is hybrid between X.509 and PGP’s web of trust.
- Each client has a list of trusted CA’s certificates and own public/private key pairs & certificates.
- Certificates must be signed by trusted CAs (e.g. VeriSign)

S/MIME Problems

- Earlier versions used mostly crippled crypto.
- S/MIME cracking screen saver released 1997.
- Original S/MIME based on patented RSA and proprietary RC2 (rejected as a standard).
- S/MIME v3 uses strong crypto and non-patented, non-proprietary technology.

Summary

- **Email Security:**
  - Secure Email
  - PGP
  - S/MIME

Threats to Security:

Malicious Software & DDoS

Malicious Software - Introduction

- Commonly called *malware, is p*erhaps the most significant security threat to organizations
- Definition: “a program that is covertly inserted into another program with the intent to destroy data, run destructive or intrusive programs, or otherwise compromise the confidentiality, integrity, or availability of the victim’s data, applications, or operating system”
- Malware can pose a threat to application programs
- Malware can also be used on compromised or malicious Web sites and servers, or in spam emails or other messages, which aim to trick users into revealing sensitive personal information

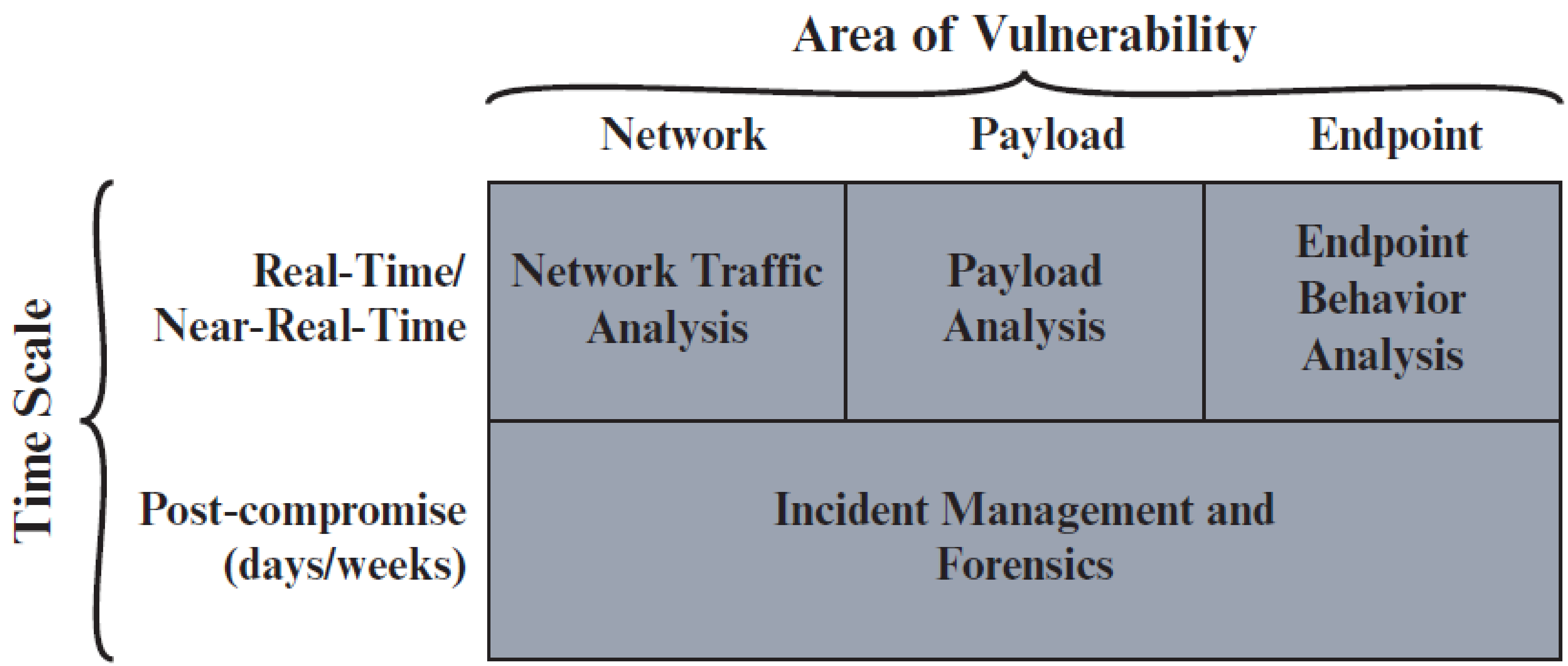
Types of Malicious Software 1

Term	Description
Virus	Malware that, when executed, tries to replicate itself into other executable code; when it succeeds the code is said to be infected. When the infected code is executed, the virus also executes.
Worm	A computer program that can run independently and can propagate a complete working version of itself onto other hosts on a network. The main differences between viruses and worms is that the worms can self-replicate and propagate without human interaction and that the worm does not integrate into existing code.
Trojan horse	A computer program that appears to have a useful function, but also has a hidden and potentially malicious function that evades security mechanisms, sometimes by exploiting legitimate authorizations of a system entity that invokes the Trojan horse program.

Type of Malicious Software 2

Term	Description
Spyware	Software that is secretly installed into an information system to gather information on individuals or organizations without their knowledge
Rootkit	A set of tools used by an attacker after gaining root-level access to a host, to conceal the attacker's activities on the host and permit the attacker to maintain root-level access.
Backdoor	Usually installed by the attackers or by a malware program, a backdoor is a program that has the ability to bypass a system's security control, allowing an attacker to access the system stealthily
Bot (Zombie)	Program that is installed on a system to launch attacks on other machines. A collection of bots that act in concert is referred to as a *botnet*

Five Elements of Malware Defence



Malware Defence

- Network Traffic Analysis: involves monitoring traffic flows to detect potentially malicious activity, involves misuse detection or anomaly detection.

- Payload Analysis: involves looking for known malicious payloads or looking for payload patterns that are anomalous

- Endpoint Behavior Analysis: involves a wide variety of tools and approaches implemented at the endpoint, i.e. antivirus software, application whitelisting.

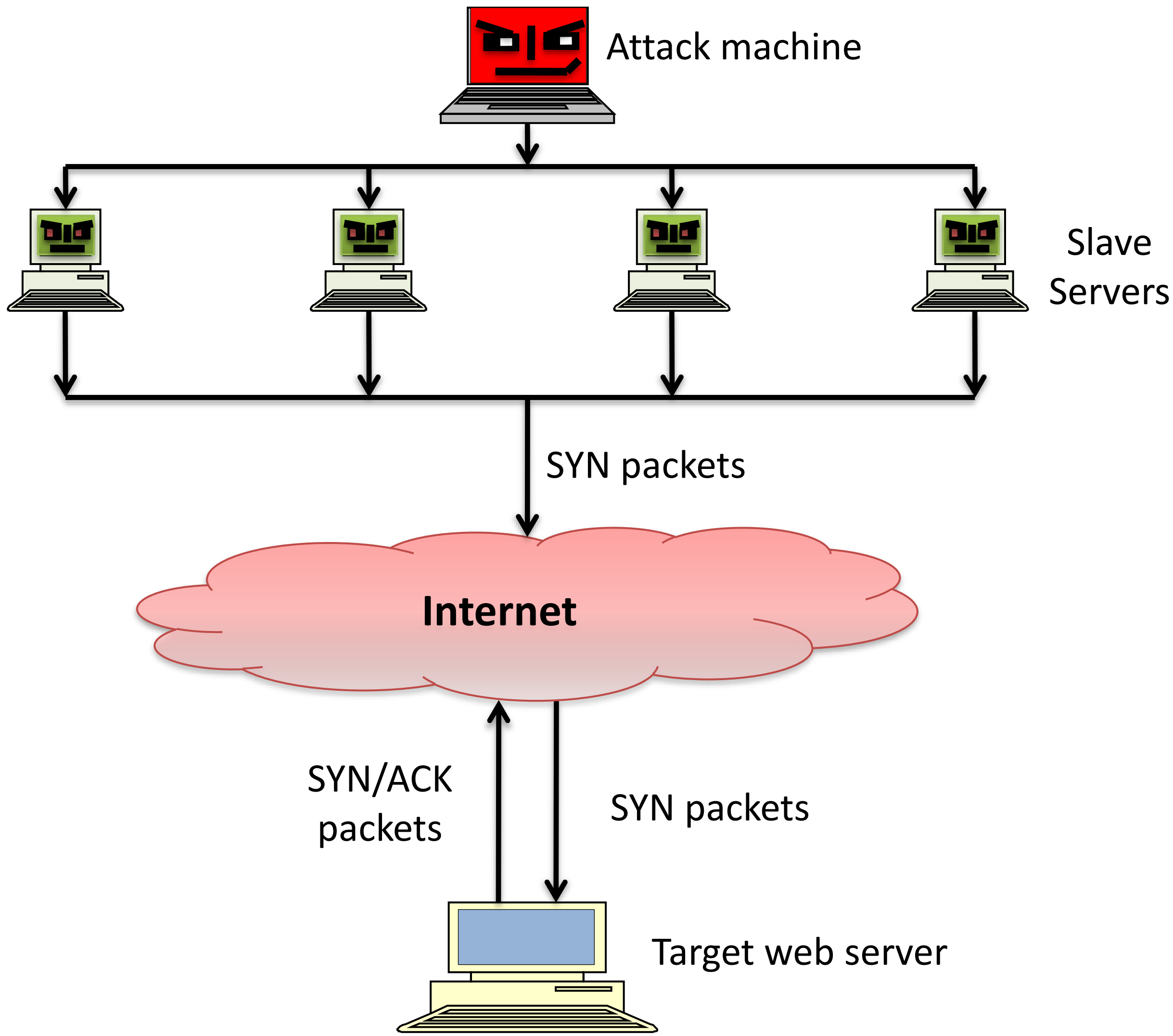
Distributed DoS Attacks

Distributed Denial of Service Attacks

- A denial of service (**DoS**) attack is an attempt to prevent legitimate users of a service from using that service. When this attack comes from a single host or network node, then it is simply referred to as a DoS attack.
- DDoS Attack make computer systems inaccessible by flooding servers, networks, or even end-user systems with useless traffic so that legitimate users can no longer gain access to those resources
- In a typical DDoS attack, a large number of compromised hosts are amassed to send useless packets
- DDoS attack examples
  – Internal Resource Attack (SYN or ICMP)
  – Direct or Reflector flooding attack

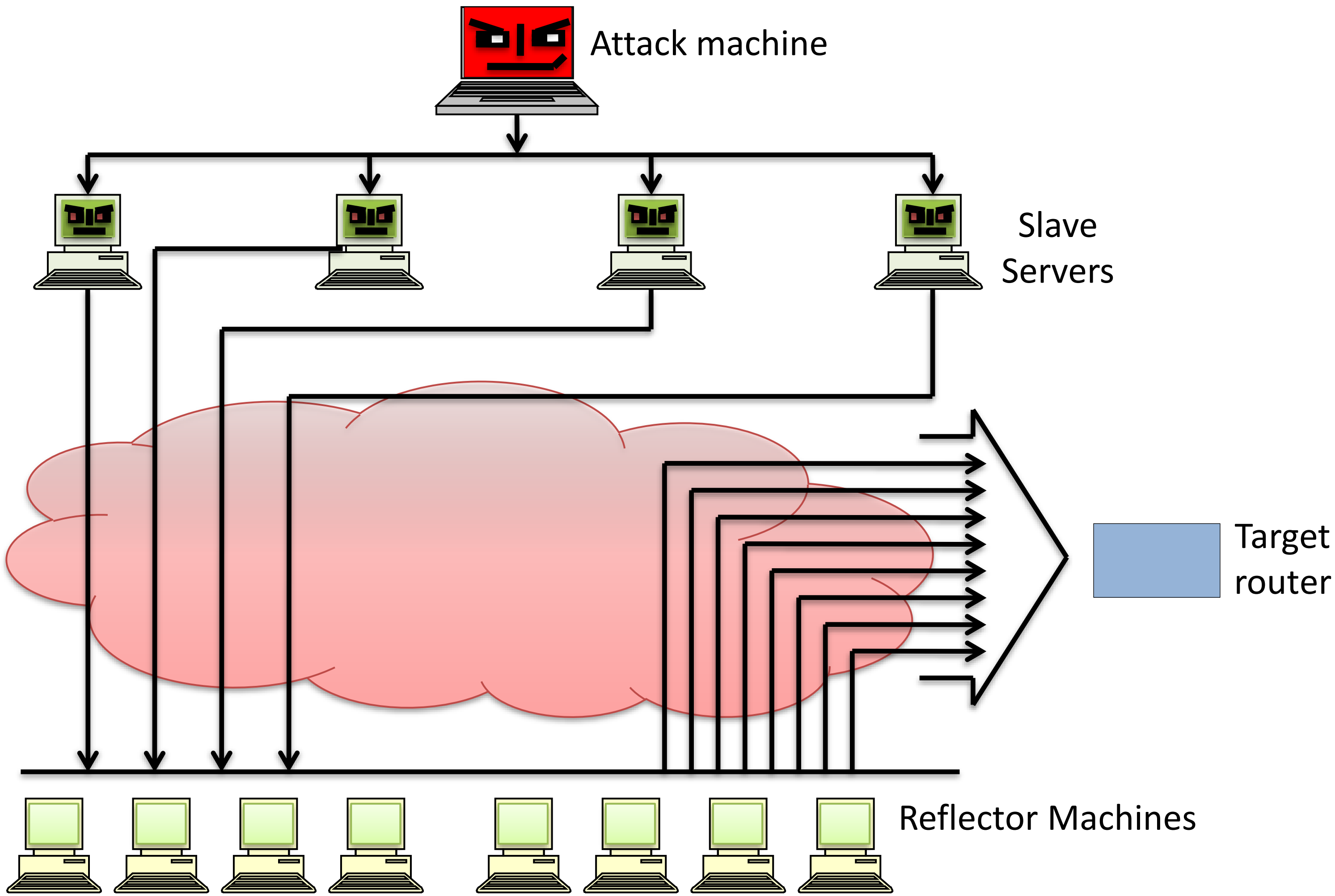
Distributed Denial of Service Attacks

- Distributed SYN flood attack



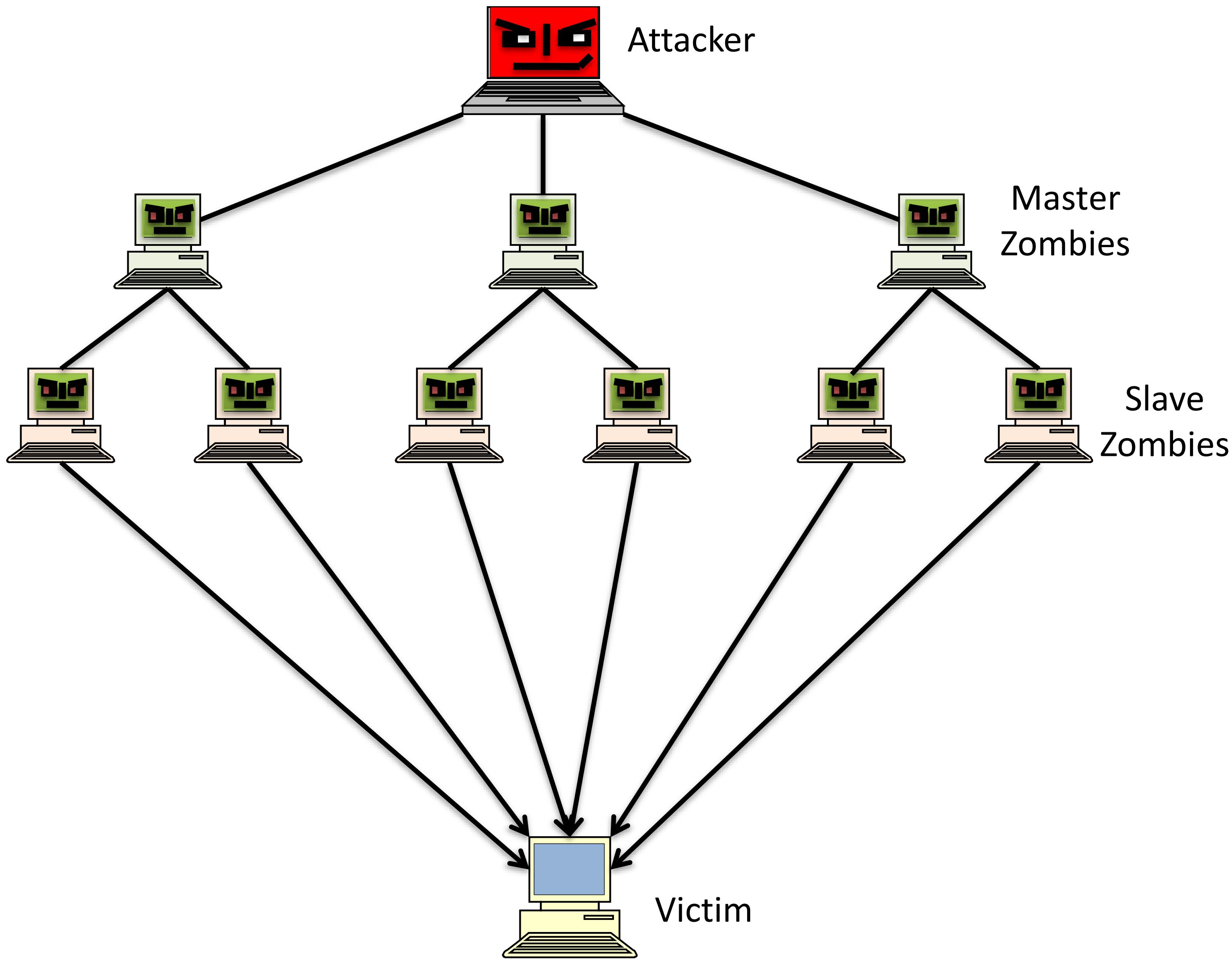
Distributed Denial of Service Attacks

- Distributed ICMP attack



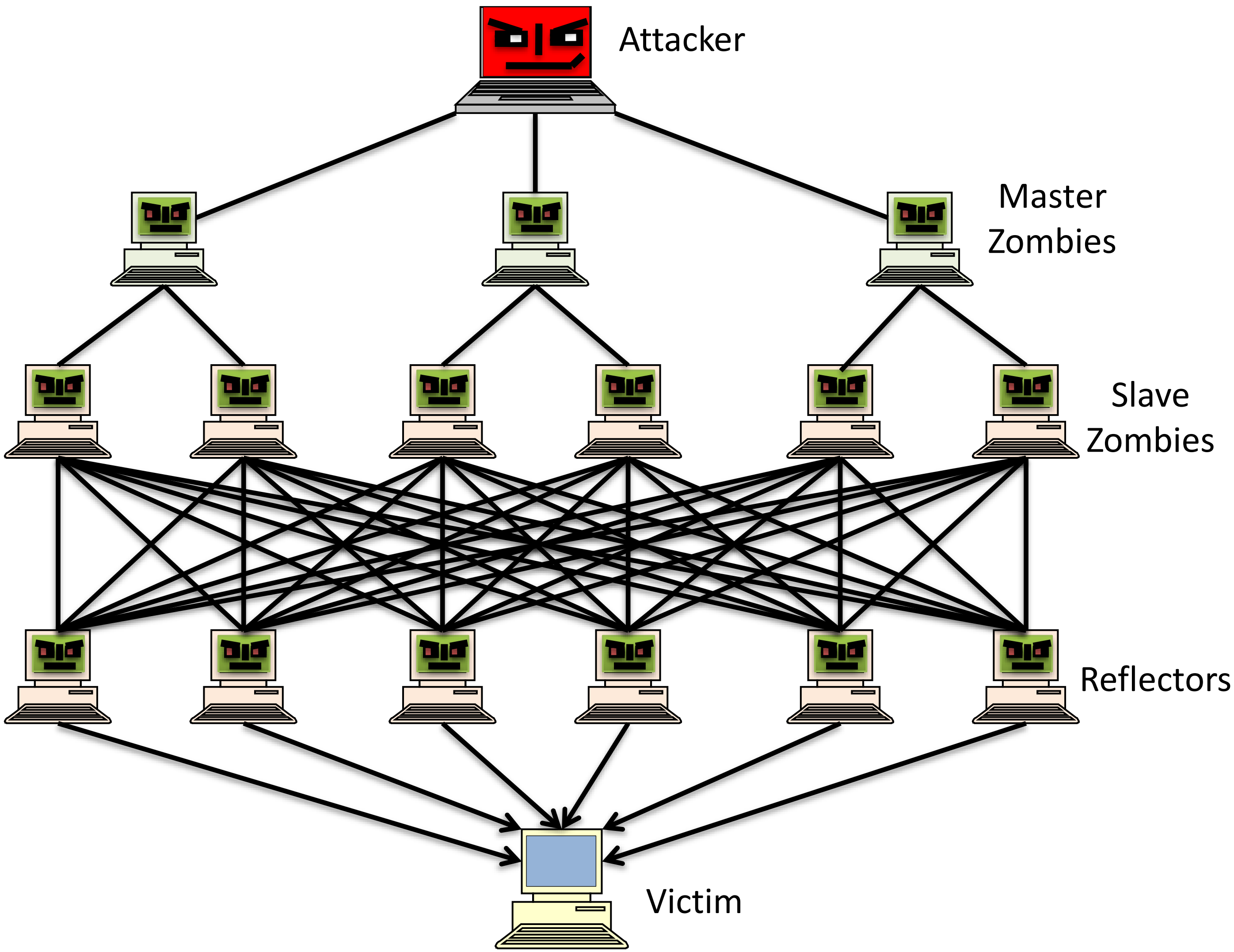
Distributed Denial of Service Attacks

- Direct DDoS attack (flooding based)



Distributed Denial of Service Attacks

- Reflector DDoS Attack (flooding based)



DDoS Countermeasures

- **Attack prevention and pre-emption** (before the attack)

Techniques include enforcing policies for resource consumption and providing backup resources available on demand

- **Attack detection and filtering** (during the attack)

These mechanisms attempt to detect the attack as it begins and respond immediately

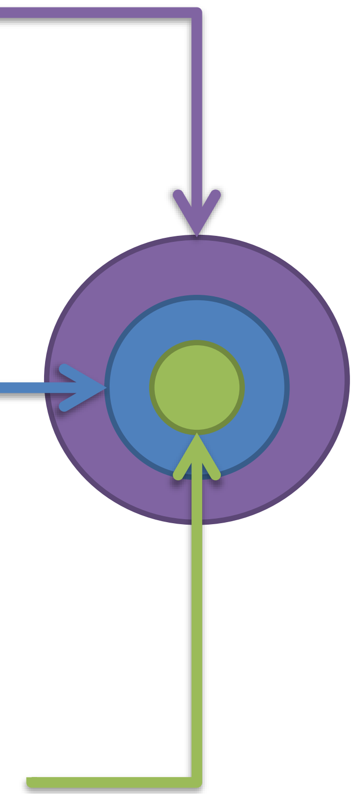
- **Attack source trace-back and identification** (during and after the attack)

This is an attempt to identify the source of the attack as a first step in preventing future attacks.

The big picture..

Information Systems Security

- **Informal**
  - Educating and training the members of organisation
- **Formal**
  - Data management or security rules
  - Management of personnel
- **Technology Based (Technical):**
  - Smart security cards, Ciphers, etc.



Review..