# Authentication based on public keys

public keys & X.509

# Authentication using public key

- Idea: use signed messages containing challenges or timestamps; signatures can be verified using public key
- Problem: it is important to guarantee knowledge of public key. In fact

1. Alice wants to be authenticated by Bob;
2. Let $K_{PT}$ Trudy's public key
3. If Trudy convinces B that the public key of A is $K_{PT}$ then Trudy can be authenticated by Bob as Alice

Solution: Public Key Infrastructure: authority that guarantees correctness of public keys.

# Authentication using public key Needham-Schroeder

$K_{PX}$: public key of X, Sig_C digital signature of C (trusted authority guarantees public keys)

Mutual authentication

1. A to C: <this is A, want to talk to B>
2. C to A: <B, $K_{PB}$, Sig_C($K_{PB}$,B)>
3. A checks digital signature of C, generates nonce N and sends to B: $K_{PB}$(N, A)
4. B decrypts (now wants to check A's identity) and sends to C: <B, A>
5. C to B: <A, $K_{PA}$, Sig_C($K_{PA}$, A) >
6. B checks C's digital signature, retrieves $K_{PA}$, generates nonce N' and sends to A: $K_{PA}$(N, N')
7. A decrypts, checks N, and sends to B: $K_{PB}$(N')

# Attack to N.-S. public key

- Trudy is a system user that can talk (being authenticated) to A, B & C
- Two interleaved excerptions of the protocol:

  R1: authentication between A and T;
  R2: authentication between T (like A) with B
- Man in the middle attack
- *T must be able to induce A to start an authentication session with T*
- Steps 1, 2, 4, 5 allow to obtain public keys
- Steps 3, 6, 7 perform authentication

# Attack to N.-S. public key

Steps 1, 2, 4 e 5 allow to know public keys

We focus on steps 3, 6, 7 of R1 and R2:

a) A-->T : step 3 of R1 sends $K_{PT}(N, A)$
b) T(like A)-->B: step 3 of R2 sends $K_{PB}(N, A)$
c) B-->T(like A): step 6 of R2 sends $K_{PA}(N', N)$
d) T-->A: step 6 of R1 sends $K_{PA}(N', N)$
e) A-->T: step 7 of R1 sends $K_{PT}(N')$
f) T(like A)-->B: step 7 of R2 sends $K_{PB}(N')$

B thinks that he is talking to A by sharing secret nonces!

# Authentication using public key Needham-Schroeder (fixed)

$K_{PX}$: public key of X, Sig_C digital signature of C (trusted authority guarantees public keys)

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4. B decrypt (now wants to check A's identity) and sends to C: <B, A>
5. C to B: <A, $K_{PA}$, Sig_C($K_{PA}$, A) >
6. B checks C's digital signature, retrieves $K_{PA}$, generates nonce N' and sends to A: $K_{PA}$(B, N, N')
7. A decrypts, checks N, and sends to B: $K_{PB}$(N')

# Why the previous attack fails

We focus on steps 3,6,7 of R1 and R2:

a) A-->T : step 3 of R1 sends $K_{PT}(N,A)$
b) T(like A)-->B: step 3 of R2 sends $K_{PB}(N,A)$
c) B-->T(like A): step 6 of R2 sends $K_{PA}(B, N',N)$
d) T-->A: EARLIER in step 6 of R1 T sends $K_{PA}(N', N)$; NOW T **CANNOT** send $K_{PA}(B, N', N)$ while is talking to A!!
e) A-->T: step 7 of R1 sends $K_{PT}(N')$
f) T(like A)-->B: step 7 of R2 sends $K_{PB}(N')$

# X.509 Authentication standard

- Part of standard known as CCITT X.500
- Defined in 1988 and several times revised (until 2000)
  - version 3
- We need directory of public keys signed by certification authority
- Define authentication protocols (see for instance [Stallings2005], or https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-X.509-201210-S!!PDF-E&type=items)
  - One-Way Authentication
  - Two-Way Authentication
  - Three-Way Authentication
- Public key cryptography and digital signatures
  - Algorithms are not part of the standard (why?)

# X.509 (one-way) authentication

Timestamp $t_A$
Session key $K_{AB}$
B's public key $P_B$
certA: certificate of A's public key, signed by certification authority

$A \rightarrow B$ : certA, $D_A$, Sig_A($D_A$)
$D_A = \langle t_A, B, P_B(K_{AB}) \rangle$

# One-way authentication (discussion)

Single transfer of information from A to B and establishes the following:

1. Identity of A and that message was generated by A
2. That message was intended for B
3. Integrity and originality (not sent multiple times) of message

- Message includes at least a timestamp $t_A$ (a nonce could be included too) and identity of B and is signed with A's private key
  - Timestamp consists of (optional) generation time and expiration time. This prevents delayed delivery of messages.
  - Nonce can be used to detect replay attacks. Its value must be unique within the expiration time of the message. B can store nonce until message expires and reject any new messages with same nonce.
- For authentication, message used simply to present credentials to B
- Message may also include information, sgnData (not shown)
  - included within signature, guaranteeing authenticity and integrity.
- Message may also be used to convey session key to B, encrypted with B's public key

# X.509 (two-ways) mutual authentication

Mutual authentication:

- A → B
  **certA, $D_A$, Sig_A($D_A$) [$D_A = <t_A, N, B, P_B(k)>$]**
  (how does A know $P_B$?)
- B → A
  **certB, $D_B$, Sig_B($D_B$) [$D_B = <t_B, N', A, N, P_A(k')>$]**
  (how does B know $P_A$?)

$t_A$, $t_B$ = timestamps, to prevent delayed delivery of messages; k, k' session keys proposed by A and B; use of nonces avoids replay attacks

criticism: in $D_A$ there is no identity of A - refer to the modified N.S. protocol

# X.509 (three-ways) mutual authentication

Mutual authentication based on nonces, useful for unsynchronised clocks (0 denotes timestamp, optional)

three messages (A → B, B → A, A → B):

1. A → B: <certA, $D_A$, Sig_A($D_A$)> [$D_A$ = <0, N, B, $P_B$(k)>]
2. B → A: <certB, $D_B$, Sig_B($D_B$)> [$D_B$= <0, N, A, N', $P_A$(k)>]
3. A → B: <B, Sig_A(N, N', B)>

Note: step 3 requires digital signature of nonces, making them tied (no replay attacks)

# Challenge-response: ISO/IEC 9798-3 Mutual authentication (earlier version, bugged)

Why does the following protocol not work?

1. B to A: $N_B$
2. A to B: certA, $N_A$, $N_B$, B, Sig_A($N_A$, $N_B$, B)
3. B to A: certB, $N_B$', $N_A$, A, Sig_B($N_B$', $N_A$, A) [not predictable by A]

"Canadian" attack (from *Protocols for Authentication and Key Establishment*, C. Boyd and A. Mathuria, Springer 2003, p. 112)

4. T(B) to A : $N_T$
5. A to T(B): certA, $N_A$, $N_T$, B, Sig_A($N_A$, $N_T$, B)
   1. T(A) to B: $N_A$
   2. B to T(A): certB, $N_B$, $N_A$, A, Sig_B($N_B$, $N_A$, A)
6. T (B) to A: certB, $N_B$, $N_A$, A, Sig_B($N_B$, $N_A$, A); T is authenticated!!

Note: use of $N_B$ in step 3 (in place of $N_B$') has the same role as the use of Bob in step 6 of original N.-S. protocol

# PKI: Public Key Infrastructure

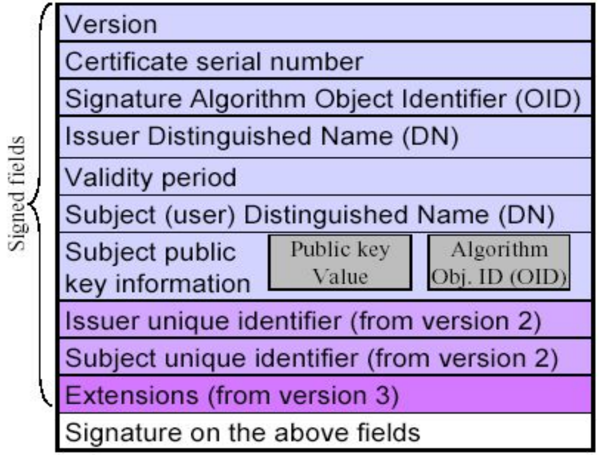
- Certificates are issued by a trusted Certification Authority (CA)
- The CA provides certificates of all users in domain
- When someone wants to know the public key of some user he/she asks the CA
  - CA provides user's public key, signing it by its own private key
- This implies it is sufficient to know one only public key (CA's public key)

Notice:

- If CA is not trusted, its certificates are useless
- Keys are not used forever, they are subject to changes
- Length of key is related to security level

# X.509 Certificates

Certification authority CA guarantees public keys:



# X.509 certificate's fields 1

- VERSION. There are currently three versions defined, version 1 for which the code is 0, version 2 for which the code is 1, and version 3 for which the code is 2.
- SERIALNUMBER. An integer that, together with the issuing CA's name, uniquely identifies this certificate.
- SIGNATURE. Specifies the algorithm used to compute the signature on this certificate. It consists of a subfield identifying the algorithm followed by optional parameters for the algorithm.
- ISSUER. The X.500 name of the issuing CA.

# X.500 name

- X.500 names look like C=US, O=company name, OU=research, CN=Alice,
  where C means *country*, O means *organization*, OU means *organizational unit*, and CN is *common name*.
- There are rules about what types of name components are allowed to be under what others.
  - The encoding uses OIDs (Object IDentifiers) for each of the name component
- There is no standard for displaying X.500 names and different applications display them differently.

# X.509 certificate's fields 2

- VALIDITY. This contains two subfields, the time the certificate becomes valid, and the last time for which it is valid.
- SUBJECT. The X.500 name of the entity whose key is being certified.
- SUBJECTPUBLICKEYINFO. This contains two subfields, an algorithm identifier, and the subject's public key.
- ISSUERUNIQUEIDENTIFIER. Optional (permitted only in version 2 and version 3, but deprecated). Uniquely identifies the issuer of this certificate.

# X.509 certificate's fields 3

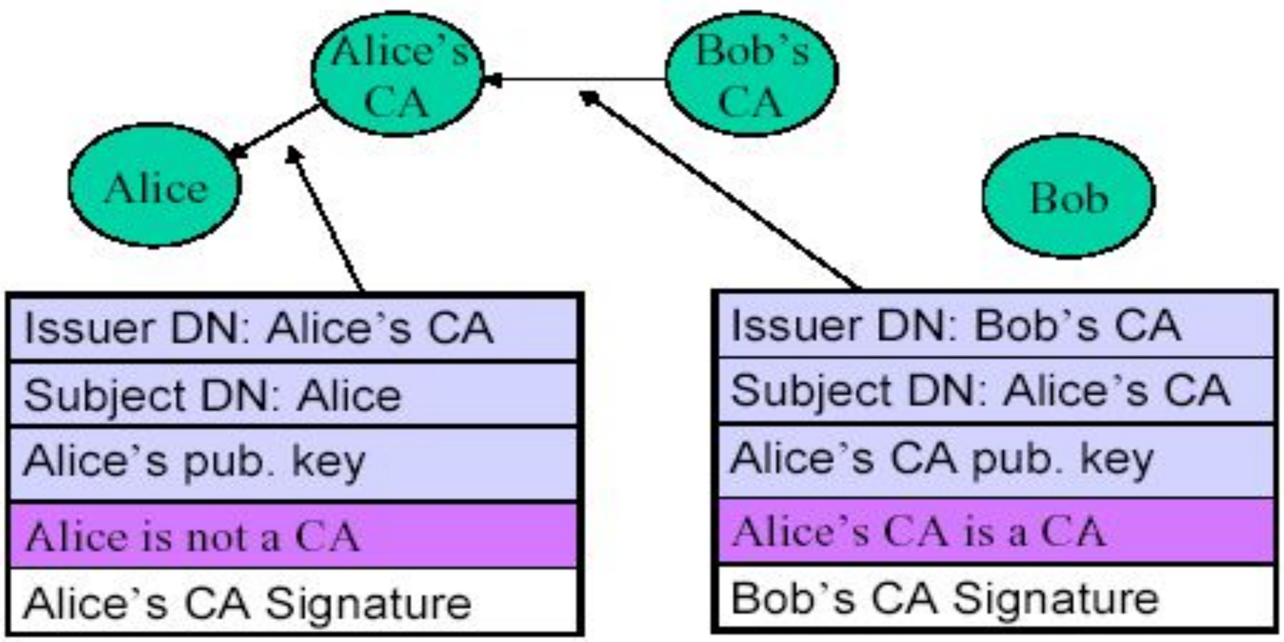
- SUBJECTUNIQUEIDENTIFIER. Optional (permitted only in version 2 and version 3, but deprecated). Uniquely identifies the subject of this certificate.
- ALGORITHMIDENTIFIER. This repeats the SIGNATURE field. Redundant!
- EXTENSIONS. These are only in X.509 version 3. X.509 allows arbitrary extensions, since they are defined by OID.
- ENCRYPTED. This field contains the signature on all but the last of the above fields.

# X.509 Certificates

- They can be easily accessed
- Certificates are modified by CA
- Certificates impossible to falsify (RSA > 2000 bit)
- If Alice and Bob share the same CA then they can know each other Public Key
- Otherwise CA form a hierarchy

# Hierarchy of CAs

How Bob gets Alice's certificate if they refer to different CAs?

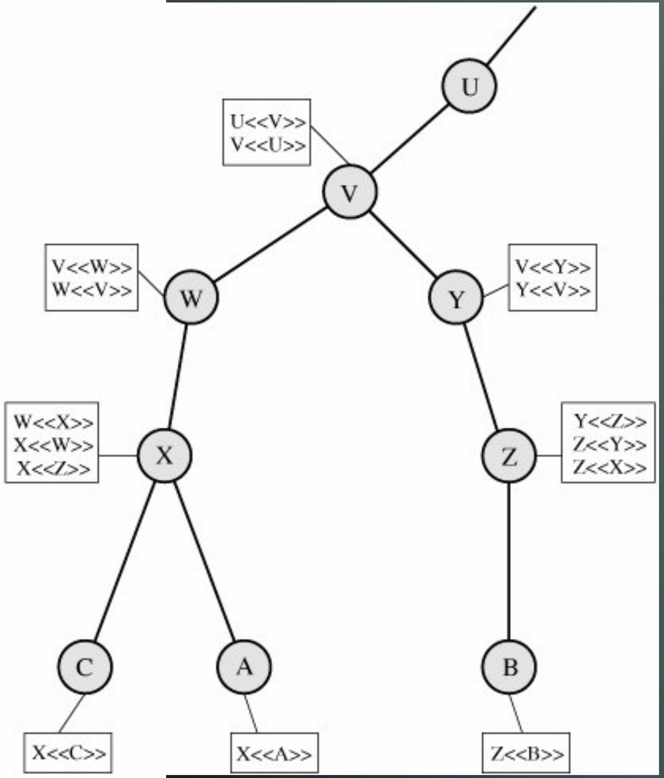


# Hierarchy of CAs

user A can acquire the following certificates from the directory to establish a certification path to B:

X<<W>> W<<V>> V<<Y>> Y<<Z>>  Z<<B>>

where A<<B>> means "the certificate of user B has been issued by certification authority A"



# Certificate revocation

Certificates are valid for a limited time (CAs want to be paid)

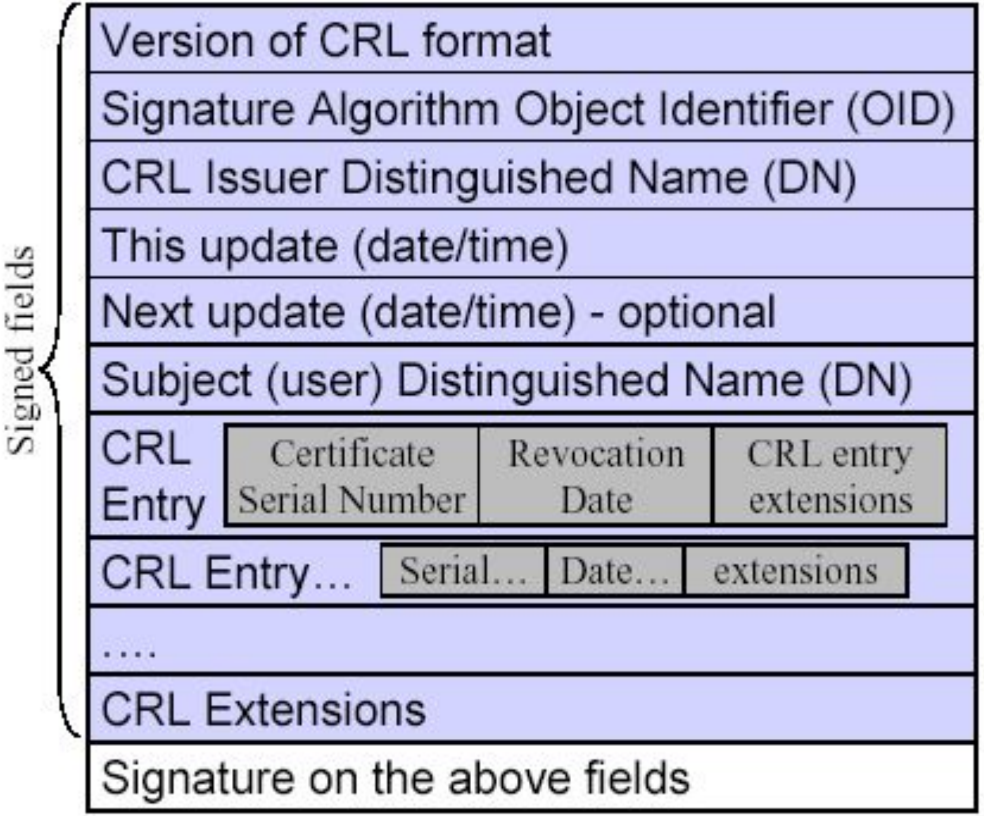
They can be revoked before the deadline:

1. User's secret key is not considered safe anymore
2. User is not certified by CA
3. CA's secret key is compromised

CRL: certificate revocation list

- Must be checked upon accessing a user certificate

# Certificate revocation



# CRL's fields

- SIGNATURE. Identical to the SIGNATURE field in certificates, this specifies the algorithm used to compute the signature on this CRL.
- ISSUER. Identical to the ISSUER field in certificates, this is the X.500 name of the issuing CA.

# CRL's fields

- THISUPDATE. This contains the time the CRL was issued.
- NEXTUPDATE. Optional. This contains the time the next CRL is expected to be issued. A reasonable policy is to treat as suspect any certificate issued by a CA whose current CRL has NEXTUPDATE time in the past.

# CRL's fields

- The following three fields repeat together, once for each revoked certificate:
  - USERCERTIFICATE. This contains the serial number of the revoked certificate.
  - REVOCATIONDATE. This contains the time the certificate was revoked.
  - CRLENTRYEXTENSIONS. This contains various optional information such as a reason code for why the certificate was revoked.

# CRL's fields

- CRLEXTENSIONS. This contains various optional information.
- ALGORITHMIDENTIFIER. As for certificates, this repeats the SIGNATURE field.
- ENCRYPTED. This field contains the signature on all but the last of the above fields.

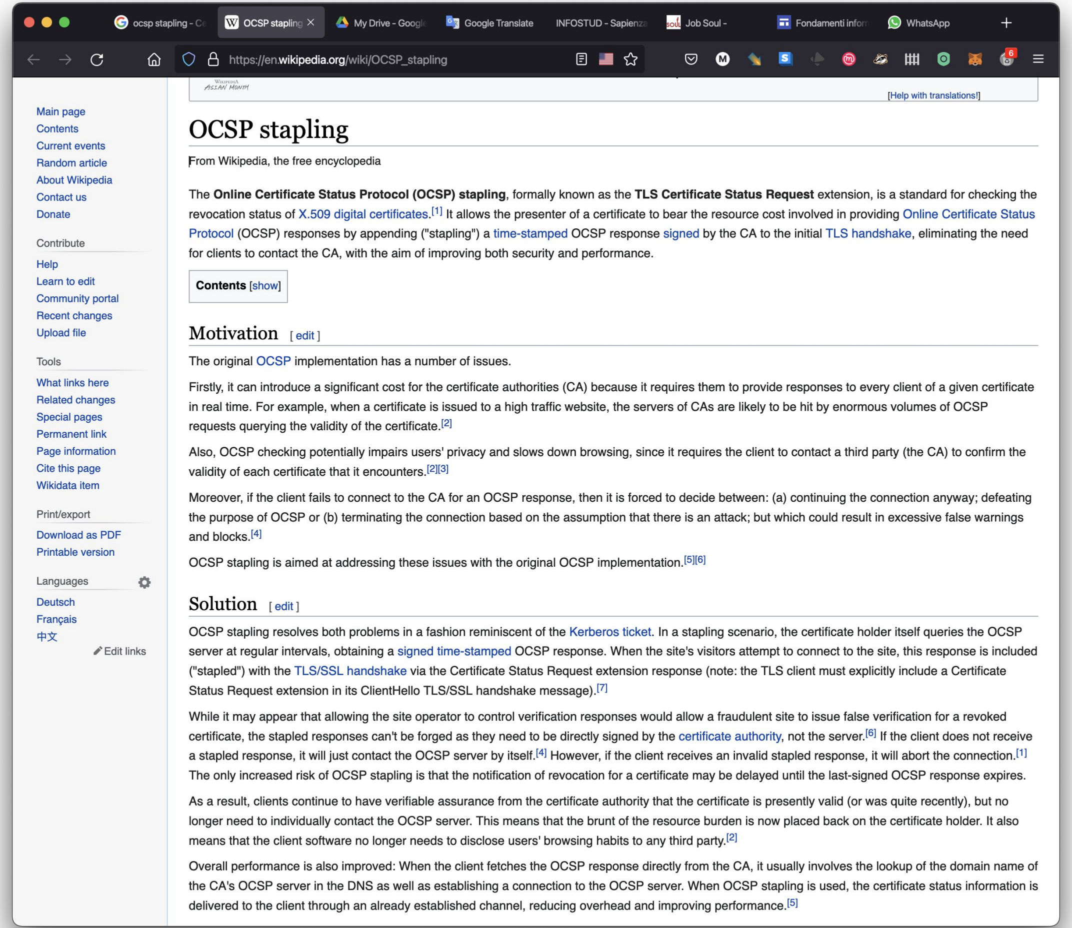
# X.509 Version 3

- In version 3 certificates have much more information:
  - email/URL, possible limitations in the use of the certificate
- Instead of adding fields for every possible new information define extensions
- Extensions:
  - Which kind of extension
  - Specification about the extension

# OCSP

- Online Certificate Status Protocol used for obtaining the revocation status of an X.509 digital certificate (RFC 6960)
  - alternative to CRL, more agile
  - cert. status provided in TLS handshake (OCSP stapling: response on revocation check, signed by legit CA)
  - URL for check provided within the cert. (Certificate Extensions -> Authority Information Access, vers. 3 only)

# OCSP stapling (Wikipedia)



https://en.wikipedia.org/wiki/OCSP_stapling

# OCSP stapling

From Wikipedia, the free encyclopedia

The **Online Certificate Status Protocol (OCSP) stapling**, formally known as the **TLS Certificate Status Request** extension, is a standard for checking the revocation status of X.509 digital certificates.[1] It allows the presenter of a certificate to bear the resource cost involved in providing Online Certificate Status Protocol (OCSP) responses by appending ("stapling") a time-stamped OCSP response signed by the CA to the initial TLS handshake, eliminating the need for clients to contact the CA, with the aim of improving both security and performance.

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## Motivation [ edit ]

The original OCSP implementation has a number of issues.

Firstly, it can introduce a significant cost for the certificate authorities (CA) because it requires them to provide responses to every client of a given certificate in real time. For example, when a certificate is issued to a high traffic website, the servers of CAs are likely to be hit by enormous volumes of OCSP requests querying the validity of the certificate.[2]

Also, OCSP checking potentially impairs users' privacy and slows down browsing, since it requires the client to contact a third party (the CA) to confirm the validity of each certificate that it encounters.[2][3]

Moreover, if the client fails to connect to the CA for an OCSP response, then it is forced to decide between: (a) continuing the connection anyway; defeating the purpose of OCSP or (b) terminating the connection based on the assumption that there is an attack; but which could result in excessive false warnings and blocks.[4]

OCSP stapling is aimed at addressing these issues with the original OCSP implementation.[5][6]

## Solution [ edit ]

OCSP stapling resolves both problems in a fashion reminiscent of the Kerberos ticket. In a stapling scenario, the certificate holder itself queries the OCSP server at regular intervals, obtaining a signed time-stamped OCSP response. When the site's visitors attempt to connect to the site, this response is included ("stapled") with the TLS/SSL handshake via the Certificate Status Request extension response (note: the TLS client must explicitly include a Certificate Status Request extension in its ClientHello TLS/SSL handshake message).[7]

While it may appear that allowing the site operator to control verification responses would allow a fraudulent site to issue false verification for a revoked certificate, the stapled responses can't be forged as they need to be directly signed by the certificate authority, not the server.[6] If the client does not receive a stapled response, it will just contact the OCSP server by itself.[4] However, if the client receives an invalid stapled response, it will abort the connection.[1] The only increased risk of OCSP stapling is that the notification of revocation for a certificate may be delayed until the last-signed OCSP response expires.

As a result, clients continue to have verifiable assurance from the certificate authority that the certificate is presently valid (or was quite recently), but no longer need to individually contact the OCSP server. This means that the brunt of the resource burden is now placed back on the certificate holder. It also means that the client software no longer needs to disclose users' browsing habits to any third party.[2]

Overall performance is also improved: When the client fetches the OCSP response directly from the CA, it usually involves the lookup of the domain name of the CA's OCSP server in the DNS as well as establishing a connection to the OCSP server. When OCSP stapling is used, the certificate status information is delivered to the client through an already established channel, reducing overhead and improving performance.[5]

# PGP: Pretty Good Privacy

Trust model for E-mail certif. (Zimmerman)

- There are no trusted CA
- Each user acts like a CA and decides for himself
- Certificates contain email addresses and public keys
- Certificates are signed by one or many users
- If you trust a sufficient number of the users signing a certificate, then you assume the certificate is good
- Each user keeps info on public keys of other users and signatures of these keys - together with trust value of the key