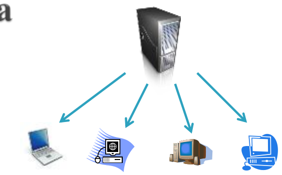
# Advanced Web Security

Data representation and PKI



## Representation of Data



- Many systems use the same data
- Systems have
  - Different architecture
  - Different OS
  - Different programs for reading/interpreting the data
- Data must be interpreted the same everywhere
- If we always know exactly what to expect it would not be much problem, but
  - Customized messages
  - Optional extensions
- Some language determining the rules is needed
  - ABNF
  - XML Schema
  - ASN.1



## Representing and Describing Data, ABNF

**ABNF – Augmented Backus-Naur Form**

- Describes some Internet protocols (HTTP, SMTP,...)
- Set of rules

rulename

```
Name = elements
```

One or more rulenames or terminal values

*Examples in HTTP*

- Version number

```
HTTP-Version = "HTTP" "/" 1*DIGIT "." 1*DIGIT
```

Terminal values

- HTTP request line

rulenames Terminal values

```
Request-Line = Method SP Request-URI SP HTTP-Version CRLF
Method = "OPTIONS" | "GET" | "HEAD" | "POST" | "PUT" | "DELETE" | "TRACE" | "CONNECT" | extension-method
extension-method = token
Request-URI = "*" | absoluteURI | abs_path | authority
...
```

**See RFC 5234 for more details**

- Ultimately, it all ends with terminal values



## Encoding ABNF

- Typically encoded using 7-bit ASCII

```
HTTP-Version = "HTTP" "/" 1*DIGIT "." 1*DIGIT
```

encoded as

```
HTTP/1.1
```

and

```
Request-Line = Method SP Request-URI SP HTTP-Version CRLF
Method = "OPTIONS" | "GET" | "HEAD" | "POST" | "PUT" | "DELETE" | "TRACE" | "CONNECT" | extension-method
extension-method = token
Request-URI = "*" | absoluteURI | abs_path | authority
...
```

can be encoded as

```
GET /index.htm HTTP/1.1
```

# XML Schema

- Another way of describing data is XML Schema
- Encoded as XML
  - XML Schema describes what a valid XML document looks like in a specific application or protocol
- Commonly used for user-defined data
  - Lots of applications in e.g., web services
- Encoding is very verbose

**XML Schema**

```
<xs:element name="phoneNumber">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="phoneID" type="xs:string"/>
      <xs:element name="number" type="xs:string"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

**Encoding**

```
<phoneNumber>
  <phoneID>Mobile</phoneID>
  <number>0701234567</number>
</phoneNumber>
```

- For both ABNF and XML schema, the encoded data is easily readable
  - But what about binary data?
  - Base64 can be used



# ASN.1

- ASN.1 – Abstract Syntax Notation One
  - Another way of describing rules
  - Widely used in telecomunications (GSM, 3G, LTE)
  - Used for certificates, encrypted/signed messages, keys etc (Main reason to focus on this here)
- Joint standard, ISO and ITU
- Built around types
- Similarities with programming languages
- Several versions during development
  - 1984, 1988, 1995, 2008
- Description and encoding are separated
  - ASN.1 for description/structure
  - BER, CER, DER, PER, XER,… for encoding

**Example**

- We want to send data regarding students at LTH between computers



# First type definition

Structures types

*type*

```
PhoneNumber ::= SEQUENCE {
  phoneID         VisibleString,
  number          NumericString
}
```

*names*

*Simple types*
*Component types*

- Two main kinds of types
  - Simple types – does not have components
  - Structured types – has component types
- There are also tagged types and e.g., CHOICE which is another type.



# Examples of Simple Types

| Type | Description | Tag |
|---|---|---|
| BOOLEAN | A Boolean which can only take one of the values 0 or 1. | 1 |
| INTEGER | An integer of any size. | 2 |
| DATE | A date in the format YYYY-MM-DD. | |
| BIT STRING | Binary data that does not have to be a multiple of 8 bits. | 3 |
| OCTET STRING | Binary data that is a multiple of 8 bytes. | 4 |
| UTF8String | A string encoded with UTF-8, allowing the use of Unicode. | 12 |
| NumericString | A string of numbers 0-9 and the “space” character. | 18 |
| VisibleString | ASCII characters other than control characters. | 26 |

- Each type has a pre-defined tag
  - Used for encoding

## Structures Types (+ CHOICE)

| Type | Description | Tag |
|---|---|---|
| CHOICE | A list of types and the value is one of the listed component types. | * |
| SEQUENCE | An ordered list of component types. The values must be given in the specified order. | 16 |
| SEQUENCE OF | Same as SEQUENCE but all components types have to be of the same type. | 16 |
| SET | An un-ordered list of distinct component types, i.e., the values can be of any order. | 17 |
| SET OF | An un-ordered list of a single component type, i.e., values can be in any order but they are always of the same type. | 17 |

- Has component types
- Tag of CHOICE is the tag of the chosen component type



## Expanding Example

```
Student ::= SEQUENCE {
  studentName      UTF8String,
  phone            SEQUENCE OF PhoneNumber
}

PhoneNumber ::= SEQUENCE {
  phoneID          VisibleString,
  number           NumericString
}
```

- One student can have several phone numbers
  - Structured type SEQUENCE OF is used
- Type ”Student” is top-level type



## Expanding Example

```
Student ::= SEQUENCE {
  studentName      UTF8String (SIZE(1..40)),
  phone            SEQUENCE OF SEQUENCE {
                     phoneID     VisibleString,
                     number      NumericString
                   }
}
```

- Explicit definition of phone number removed
- Restriction on size of string, called subtype



## Object Identifiers

```
id-sha256  OBJECT IDENTIFIER  ::=  { joint-iso-itu-t(2)
     country(16) us(840) organization(1) gov(101) csor(3)
     nistalgorithm(4) hashalgs(2) 1 }
```

- Globally unique identifier
  - Algorithms
  - Semantics meanings
  - Protocols
  - …
- Global tree, similar to DNS in many ways
  - Responsibility for one subtree can be delegated
  - Distributed storage
- Branches are numbered from 0, and sometimes given a name
- OIDs used are assumed known to communicating systems

# Expanding Example

- Keywords DEFAULT and OPTIONAL
  - DEFAULT gives default value if none is chosen
  - OPTIONAL says that it is optional to include data for this type
- Enumerated type
  - Give explicit semantic meaning to numbers (or the other way around if you wish)
- OID for a student – Should be in the LTH subtree



```
Student ::= SEQUENCE {
  studentName      UTF8String (SIZE(1..40)),
  studentID        OBJECT IDENTIFIER,
  program          ENUMERATED {
                     C(0), D(1), E(2), F(3), Pi(4)
                   },
  phone            SEQUENCE OF SEQUENCE {
                     phoneID     VisibleString,
                     number      NumericString
                   },
  status           StudentStatus,
  finishedCourses  SEQUENCE OF SEQUENCE {
                     courseInfo  Course,
                     grade       VisibleString
                                 ("G", "VG", "3", "4", "5")
}
StudentStatus ::= SEQUENCE {
  hp              INTEGER,
  avgGrade        REAL (3.00..5.00),
  active          BOOLEAN DEFAULT TRUE,
  comment         UTF8String OPTIONAL
}
```



# Modules, Importing, Exporting

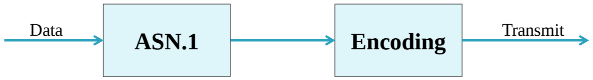
```
Student-module
 { ... }
DEFINITIONS
         AUTOMATIC-TAGS ::=
BEGIN

EXPORTS Student;

IMPORTS Course FROM LTH-module { ... };

Student ::= SEQUENCE {
     ...
}

END
```

- Import definitions from other modules
- Allow exporting definitions in this module
  - If EXPORTS is not used, everything can be exported



# Encoding

- ASN.1 can be used to structure the data and inform about what type of data it is
- Actual encoding of data is a separate process
  - Encoding method can be chosen suitably
- Type of encoding must be agreed upon or predetermined by protocol




- ASN.1 has more encoding flexibility than ABNF and XML Schema
  - It can even use XML

## BER Encoding

- Basic Encoding Rules
  - Original encoding
- More efficient than text based encodings
- Important characteristic: Many encodings are possible for the same data (but decoding is unique)
- Type-Length-Value (TLV)
  - Also called Tag-Length-Value

| Type | Length | Value | End of Value |
|---|---|---|---|

Each is one or more bytes

Maybe, depends on length encoding



## BER, Encoding the type

- Type defines what is encoded (Boolean, Integer, Sequence, UTF8String etc)
- Identifier byte
- **Class**
  - UNIVERSAL (built-in)
  - Context-specific (chosen by user)
- **P/C**
  - *Primitive:* value is the value of the type
  - *Constructed:* value is a set of TLVs (e.g., a Sequence)
- **Number** is tag value
- Examples:
  - SEQUENCE: 0x30
  - BOOLEAN: 0x01

| 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| Class | | P/C | Number | | | | |

Class of the tag

Tag value

Primitive (0) or Constructed (1)

Larger tag numbers are possible (see notes)

| Type | Length | Value | End of Value |
|---|---|---|---|



## BER, Encoding the Length

- Short Definite Form `0xxxxxxx` Max length of value = 127 bytes
- Long Definite Form

`1xxxxxxx` `xxxxxxxx` - - - - - - `xxxxxxxx`

Number of bytes that gives the length

- Indefinite Form

`10000000` *value* `00000000` `00000000`

  - Can only be used for encoding of constructed types

| Type | Length | Value | End of Value |
|---|---|---|---|



## BER, Encoding the Value

- Encoding of value will depend on the value
  - Booleans: TRUE is non-zero, FALSE is zero
    - TRUE can be TLV encoded as 01 01 FF
  - Integers: Encoded as two-complement with least number of bytes necessary
    - -2 can be TLV encoded as 02 01 FE
  - VisibleString is encoded as the ASCII representation
    - Can be split into segments with an outer constructed TLV
    - ”string” can be TLV encoded as 1A 06 73 74 72 69 6e 67
    - …or as 3A 80 1A 03 <u>73 74 72</u> 1A 03 <u>69 6e 67</u> 00 00

      T L T L V T L V

| Type | Length | Value | End of Value |
|---|---|---|---|

# DER and CER

- ”Problem” with BER: Decode → Encode can give different encoding
- Examples:
  - Boolean true is any non-zero byte
  - Long definite form can be given in several ways

130 = 10000001 10000010

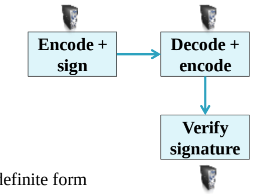
130 = 10000011 00000000 00000000 10000010

  - Sometimes any form of length encoding can be used
  - Strings can be divided at arbitrary places
- What about digital signatures then?
  - Moving data between platforms/programs should always give same encoding, otherwise signature is invalid



# DER and CER

- Always unique encodings
  - Boolean TRUE is always FF
  - Members in SET sorted by tag number




**DER (Distinguished Encoding Rules)**

- Examples:
  - Length always encoded as shortest possible definite form
  - Strings always in primitive form (no splitting)
- Certificates are often in DER format
  - Can be stored in PEM (base64 of DER)

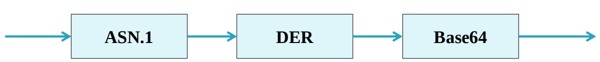
**CER (Canonical Encoding Rules)**

- Examples:
  - Length encoding is indefinite for all constructed encodings
  - Shortest possible definite for primitive encodings
  - Strings are always split into chunks of 1000 bytes



# Certificate in PEM format


```
-----BEGIN CERTIFICATE-----
MIIDJjCCAo+gAwIBAgIQI4VkKSGTgB5hicRRonT79zANBgkqhkiG9w0BAQUFADBM
MQswCQYDVQQGEwJaQTElMCMGA1UEChMcVGhhd3RlIENvbnN1bHRpbmcgKFB0eSkg
THRkLjEWMBQGA1UEAxMNVGhhd3RlIFNHQyBDQTAeFw0xMTA3MjEwMDAwMDBaFw0x
MzA3MTgyMzU5NTlaMG0xCzAJBgNVBAYTAlVTMRMwEQYDVQQIEwpDYWxpZm9ybmlh
MRYwFAYDVQQHFA1Nb3VudGFpbiBWaWV3MRMwEQYDVQQKFApHb29nbGUgSW5jMRww
GgYDVQQDFBNhY2NvdW50cy5nb29nbGUuY29tMIGfMA0GCSqGSIb3DQEBAQUAA4GN
ADCBiQKBgQDVFFeglkCfhAjGZo3u7OMDsmaFrF27HO8Vk/0fIKcQSSRbOdJgyJrc
wM5ANOZZlbZSUP4IJUVXc1867V/ftlydipxi/Q9hvtz2hx2AnX98FxN3ZDxH84ck
H2Bh4IERRuTcUFw5U+ZoPYY8VYfIvvyHE9laql3MPwfBdM3CXicWEQIDAQABo4Hn
MIHkMHIGCCsGAQUFBwEBBGYwZDAiBggrBgEFBQcwAYYWaHR0cDovL29jc3AudGhh
d3RlLmNvbTA+BggrBgEFBQcwAoYyaHR0cDovL3d3dy50aGF3dGUuY29tL3JlcG9z
aXRvcnkvVGhhd3RlX1NHQ19DQS5jcnQwDAYDVR0TAQH/BAIwADA2BgNVHR8ELzAt
MCugKaAnhiVodHRwOi8vY3JsLnRoYXd0ZS5jb20vVGhhd3RlU0dDQ0EuY3JsMCgG
A1UdJQQhMB8GCCsGAQUFBwMBBggrBgEFBQcDAgYJYIZIAYb4QgQBMA0GCSqGSIb3
DQEBBQUAA4GBAIT777A4x7Tmu3RBNGxSbw73e2fU162n7wM278BA3oDTCqY8ycOe
MVIH6g9EY+pRwtDOm6FtmfgpOSxAmGcSjKe/QzDSAmOz+Aw2hVCPKcKHzebw6lfy
pIEOlLDYRmcsIK62iWSmsNqOz9QJf1fcnDIFBmKyCBT+i+oRE7z3O371
-----END CERTIFICATE-----
```




# PER

- BER, CER and DER are not very efficient
  - Booleans only require 1 bit
  - Restricted integers can be efficiently encoded
    - INTEGER (79..82) could be encoded with 2 bits
  - We do not need to explicitly state the type
    - It is clear from the ASN.1 structure
- **PER (Packed Encoding Rules)** can encode the following using 1 byte

```
Example ::= SEQUENCE {
  a           BOOLEAN,
  b           INTEGER (27..34),
  c           SEQUENCE {
                    c1     BOOLEAN,
                    c2     BOOLEAN,
                    c3     INTEGER (150..153)
              }
}
```

# Tagging

- We are returning to ASN.1 now
- Built-in types have pre-defined tags
  - Not always enough

```
Dessert ::= CHOICE {
  a         [0] INTEGER
  b         [1] INTEGER
  c         [2] INTEGER
}
```

- Explicit tagging (default) – Adds outer tagging environment
  - Seen as structured type T L T L V
  - Read as ”in addition to”
- Implicit tagging – changes the default tag
  - Read as ”instead of”
  - Default can be changed to implicit
- Tagging can be automated (AUTOMATIC-TAGS)
  - Tagging determined by rules (start with 0 and increment)



# CMS

- Cryptographic Message Syntax
- Standard for representing signed, hashed and/or encrypted messages
- Originates in PKCS 7 – now IETF standard (RFC 5652)
- Uses BER as encoding rules (mostly)
- Used in e.g., S/MIME (encrypted/signed emails)
- *ContentInfo* is the top level type

```
ContentInfo ::= SEQUENCE {
  contentType ContentType,
  content [0] EXPLICIT ANY DEFINED BY contentType
}

ContentType ::= OBJECT IDENTIFIER
```



# CMS, ContentTypes

**6 different types** (can be nested)

- **Data Type** – String of bytes
- **Signed-Data Type** – Data with digital signature(s)
- **Enveloped-Data Type** – Encrypted data and an encrypted encryption key
  - Several recipients → encryption key is encrypted for each recipient
- **Digested-Data Type** – Data with a message digest
- **Encrypted-Data Type** – Encrypted data without encrypted encryption key
- **Authenticated-Data Type** – Data with a MAC of the data and an encrypted authentication key
  - Several recipients → authentication key is encrypted for each recipient



# SignedData Type

- Data which is digitally signed
  - Several signers for same data is possible

```
SignedData ::= SEQUENCE {
  version           CMSVersion,
  digestAlgorithms  SET OF DigestAlgorithmIdentifier,
  encapContentInfo  SEQUENCE {
                       eContentType ContentType,
                       eContent [0] EXPLICIT OCTET STRING OPTIONAL },
  certificates [0]  IMPLICIT CertificateSet OPTIONAL,
  crls         [1]  IMPLICIT RevocationInfoChoices OPTIONAL,
  signerInfos       SET OF SignerInfo
}
```

## SignerInfo Type

- Gives information about each signer

```
SignerInfo ::= SEQUENCE {
  version               CMSVersion,
  sid                   SignerIdentifier,
  digestAlgorithm       DigestAlgorithmIdentifier,
  signedAttrs    [0]    IMPLICIT SignedAttributes OPTIONAL,
  signatureAlgorithm    SignatureAlgorithmIdentifier,
  signature             SignatureValue,
  unsignedAttrs [1]     IMPLICIT UnsignedAttributes OPTIONAL }


SignerIdentifier ::= CHOICE {
  issuerAndSerialNumber IssuerAndSerialNumber,
  subjectKeyIdentifier [0] SubjectKeyIdentifier
}
```



## PKCS #12 – Personal information

- Represent personal information
- Uses parts of CMS and adds additional features
- Four possibilities for protection:

**Public key**

1. *Public key privacy mode* – encrypt content with symmetric key, encrypt key with public key
2. *Public key integrity mode* – Digital signature

**Symmetric key**

1. *Password privacy mode* – Encrypt with symmetric key derived from password
2. *Password integrity mode* – Use MAC with key derived from password



## PKCS #12

- Top-level type: Personal Information Exchange (PFX)

```
PFX ::= SEQUENCE {
  version       INTEGER,
  authSafe      ContentInfo,
  macData       MacData OPTIONAL }
```

- MacData only used for Password Integrity Mode

```
MacData ::= SEQUENCE {
  mac           DigestInfo,
  macSalt       OCTET STRING,
  iterations    INTEGER DEFAULT 1 }
```

- ContentInfo is either
  - SignedData – Public Key Integrity Mode
  - Data – Password Integrity Mode

Content here is called **AuthenticatedSafe**



## PKCS #12

- AuthenticatedSafe

```
AuthenticatedSafe ::= SEQUENCE OF ContentInfo
```

- ContentInfo
  - EnvelopedData – Public-Key Privacy Mode
  - Encrypted Data – Password Privacy Mode
  - Data – no encryption
- Content is a sequence of SafeBags
  - **KeyBag** – A PKCS #8 private key.
  - **PKCS8ShroudedKeyBag** – A PKCS #8 encrypted private key.
  - **CertBag** – A certificate.
  - **CRLBag** – A Certificate Revocation List.
  - **SecretBag** – A personal secret.
  - **SafeContents** – Allows for nesting the other types instead of just putting them in a sequence.

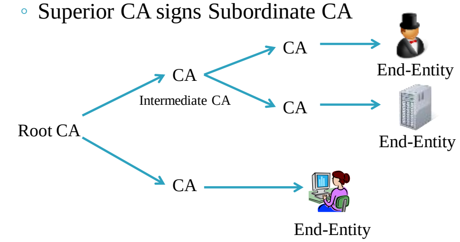
# PKI

- A public key infrastructure includes all aspects of certificates
  - Who signs
  - How they are signed
  - How they are revoked
  - How they are stored
  - How keys are generated
- Different profiles can have different rules
  - PKIX – uses X.509 certificates (Internet PKI profile)
  - Many countries have their own profile



# PKI Participants

- End-Entity – User/application where the private key cannot be used to sign certificates
- CA (Certification Authority) – Issues certificates
  - Root CA is on top
  - Superior CA signs Subordinate CA




*Hierarchical PKI architecture*



# PKI Participants, optional

- RA (Registration Authority)
  - Does not sign certificates
  - CA can delegate management functions to an RA
    - Verify identity
    - Assigning names, generating keys, storing keys, reporting revocation information
- CRL Issuer
  - Certificate Revocation Lists are used to revoke certificates
  - Typically, the CA issues a CRL
  - CA can delegate CRL issuing to another party



# Certificate Requests

- Two main variants: PKCS#10 and CRMF

```
CertReqMsg ::= SEQUENCE {
  certReq   CertRequest,
  popo      ProofOfPossession  OPTIONAL,
  regInfo   SEQUENCE SIZE(1..MAX) of AttributeTypeAndValue OPTIONAL
}

CertRequest ::= SEQUENCE {
  certReqId     INTEGER,
  certTemplate  CertTemplate,
  controls      Controls OPTIONAL
}
```

**CRMF**

- ID maps request ↔ response
- *Template* are the fields in the certificate that are filled in by requester
  - Public key, subject name, some extensions
- Controls can be used to e.g., authenticate the requester
- Proof of possession allows requester to prove ownership of private key
  - Many ways possible, e.g., signature on request (should depend on key usage)
- RegInfo can have additional information (contact info, billing info etc)

# X.509 Certificate

```
Certificate ::= SEQUENCE  {
  tbsCertificate       TBSCertificate,
  signatureAlgorithm   AlgorithmIdentifier,
  signatureValue       BIT STRING
}

TBSCertificate ::= SEQUENCE  {
        version         [0]  EXPLICIT Version DEFAULT v1,
        serialNumber         CertificateSerialNumber,
        signature            AlgorithmIdentifier,
        issuer               Name,
        validity             Validity,
        subject              Name,
        subjectPublicKeyInfo SubjectPublicKeyInfo,
        issuerUniqueID  [1]  IMPLICIT UniqueIdentifier OPTIONAL, -- v2 or v3
        subjectUniqueID [2]  IMPLICIT UniqueIdentifier OPTIONAL, -- v2 or v3
        extensions      [3]  EXPLICIT Extensions OPTIONAL        -- v3
}
```

same

- signatureAlgorithm determines the structure of the signatureValue BIT STRING



# Extensions

```
Extension ::= SEQUENCE  {
  extnID      OBJECT IDENTIFIER,
  critical    BOOLEAN DEFAULT FALSE,
  extnValue   OCTET STRING
}
```

- OID to define the extension
- Critical determines how important the extensions is
  - Applications must not process unrecognized critical extensions

**Some Extensions**

- *Authority key identifer (non-critical)* – identify issuer’s public key if it has several
- *Key usage (critical)* – Specify purpose of public key (separating keys gives some damage control)
  - Data encryption
  - Signatures
    - Data
    - Certificates
    - CRLs
- *Subject (Issuer) Alternative Name (critical or non-critical)* – Extra name for subject (issuer)
- *Basic Constraints (critical or non-critical)* – If certificate is CA



# Representing a Public Key

- SubjectPublicKeyInfo given by

```
SubjectPublicKeyInfo ::= SEQUENCE  {
  algorithm            AlgorithmIdentifier,
  subjectPublicKey     BIT STRING
}
```

- The BIT STRING is the DER encoding of the public key specified by the algorithm OID
- Example, RSA

```
RSAPublicKey ::= SEQUENCE {
  modulus            INTEGER,     -- n
  publicExponent     INTEGER      -- e
}
```

- ASN.1 encoding defines how integers are represented



# Representing a Private Key

- Not in certificates

```
RSAPrivateKey ::= SEQUENCE {
  version           Version,
  modulus           INTEGER, -- n
  publicExponent    INTEGER, -- e
  privateExponent   INTEGER, -- d
  prime1            INTEGER, -- p
  prime2            INTEGER, -- q
  exponent1         INTEGER, -- d mod (p-1)
  exponent2         INTEGER, -- d mod (q-1)
  coefficient       INTEGER, -- (inverse of q) mod p
  otherPrimeInfos   OtherPrimeInfos OPTIONAL
}
```

- In theory, only privateExponent and modulus needed to decrypt and sign
  - Other values can be used to speed up decryption/signing
- Knowing this layout can be useful in home assignment C

# Certificate Revocation List (CRL)

- List certificates that are no longer valid
  - Expired certificates are not listed
- Maintained by the CA, but can delegate to CRL issuer
- Should be updated often
- **Scope of CRL:** The category of certificates that the CRL should cover
  - Can depend on CA, subjects, reason for revocation etc
- **Complete CRL:** All revoked certificates within scope are included
- **Indirect CRL:** Contains revoked certificates issued by some other CA
- **Delta CRL:** Contains certificates revoked after issuance of some complete CRL (**base CRL**)



# CRL

- ASN.1 description of a CRL

```
CertificateList ::= SEQUENCE  {
  tbsCertList          TBSCertList,
  signatureAlgorithm   AlgorithmIdentifier,
  signatureValue       BIT STRING
}

TBSCertList ::= SEQUENCE  {
  version                 Version OPTIONAL,
  signature               AlgorithmIdentifier,
  issuer                  Name,
  thisUpdate              Time,
  nextUpdate              Time OPTIONAL,
  revokedCertificates     SEQUENCE OF SEQUENCE  {
       userCertificate         CertificateSerialNumber,
       revocationDate          Time,
       crlEntryExtensions      Extensions OPTIONAL
                          } OPTIONAL,
  crlExtensions      [0]  EXPLICIT Extensions OPTIONAL
}
```



# Extensions

**CRL entry extensions**

- *Reason code* – Why the certificate was revoked
- *Invalidity date* – When did the certificate become invalid
- *Certificate Issuer* – Give the CA of the certificate (useful for indirect CRLs)

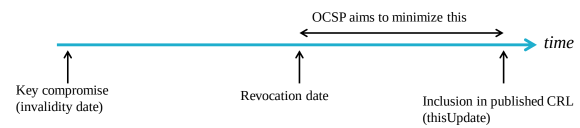
**CRL extensions**

- *CRL number (non-critical)* – sequene number for CRL
- *Delta CRL Indicator (critical)* – Points to CRL number of the base CRL (used for delta CRLs)
- *Freshest CRL (non-critical)* – Points to a delta CRL (used for complete CRLs)



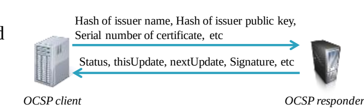
# OCSP

- Online Certificate Status Protocol
- Alternative to CRL



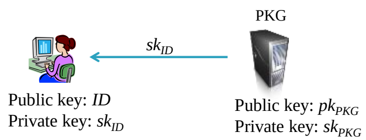

- Compromised private keys can have huge consequences in e.g., financial transactions

- Nonce can optionally be included
- Request can be signed
- Status = good/revoked/unknown



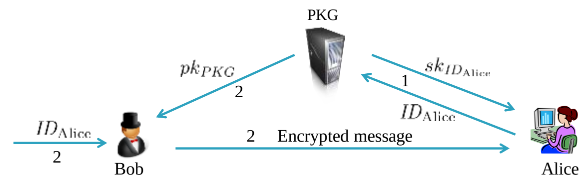
# Avoiding PKI

- Is it possible to have asymmetric cryptography without an underlying PKI?
- Identity Based Cryptography (IBC)
  - Identity Based Signatures (IBS)
  - Identity Based Encryption (IBE)
- Use identity as public key
  - Can be email address or some other identifying info
- Use Private Key Generator (PKG)






# Identity Based Encryption

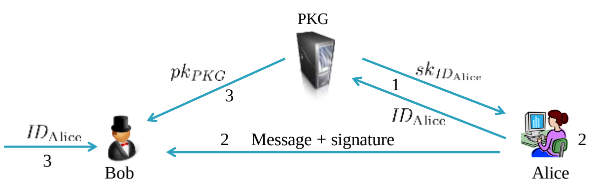



1. Alice proves she owns ID and receives her private key
2. Bob uses Alice's ID and PKG's public key to encrypt message to Alice
3. Alice decrypts using her private key

- Steps 1 and 2 can be interchanged



# Identity Based Signatures




1. Alice proves she owns ID and receives her private key
2. Alice uses her private key to sign message
3. Bob verifies signature using PKG's public key and Alice's ID



# Properties of IBC

**Advantage**

- No need for complete PKI – just have to trust the PKG

**Drawbacks**

- Not possible to revoke IDs (or at least difficult)
  - How do we revoke an email address, personnummer, fingerprint?
  - Possible to add time stamps to ID (structure and rules must be known to users)
- PKG has access to private key (called key escrow)
  - Problems with non-repudiation
  - Also a feature – the PKG can help to decrypt

## Other Solutions

- *Certificate based encryption*
  - Certificate needed in order to decrypt
  - Revoked certificate → not possible to decrypt
  - Not necessary to check public key before encryption
- *Certificateless encryption*
  - PKG creates half private key, user creates half
  - No key escrow
- See references in lecture notes for more details