

HPS / GWDG



Jonathan Decker

Certificates and PKI

Simple in Principle - Complicated in Praxis

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Overview

- We use complex math to build a cryptographic system
- Enables TLS (and HTTPS)
- Universally applicable in networks
- Identify devices and code
- Build on top of public-private-key cryptography
- Simple concept, complicated standards

Public-Private-Key Cryptography

- Also called Asymmetric Cryptography
- Use math to generate key pairs
- Encrypt with one
 - Decrypt with the other
- Encrypted messages give no hint on the key itself
- Public key can be shared
- Private key must stay private
- Use someone's public on a message
 - It can only be read with the private key

Notes on Asymmetric Cryptography

It is slow compared to symmetric crypto

- It makes sense if you see the math
- Commonly used to establish a shared secret between client and server
 - Shared secret enables symmetric cryptograhpy
- Verifying the receiver across a network is taken for granted nowadays
- Thanks number theory

Public Key Infrastructure

Who makes the Terminology - The IETF

IETF (Internet Engineering Task Force)

Founded in 1986

- Develop voluntary standards
- Publishes technical documents RFCs
- RFC (Request For Comments)
 - Historical acronym now RFC means RFC

RFC 4949 - 1/3

Entity

- "An active part of a system a person, a set of persons (e.g., some kind of organization), an automated process, or a set of processes that has a specific set of capabilities."
- Anything that exists logically or conceptually
 - Your computer, your code, you yourself
- Can be a server, software package, email contact

Identity

- "The collective aspect of a set of attribute values (i.e., a set of characteristics) by which a system user or other system entity is recognizable or known."
- Do not confuse with Identifier
- Identifier is a unique key representing an identity

RFC 4949 - 2/3

Claim

- An entity may declare an attribute
- "My name is Max Mustermann"
- Another entity may Authenticate a claim

Authentication

- Process of confirming the truth of a claim
- When you login, you claim to be a user
 - And verify the claim by giving your password

End Entity or End User

"A system entity that is the subject of a public-key certificate and that is using, or is permitted and able to use, the matching private key only for purposes other than signing a digital certificate; i.e., an entity that is not a CA."

RFC 4949 - 3/3

Certificate Authority (CA)

An entity that issues certificates to subscribers

Subscriber

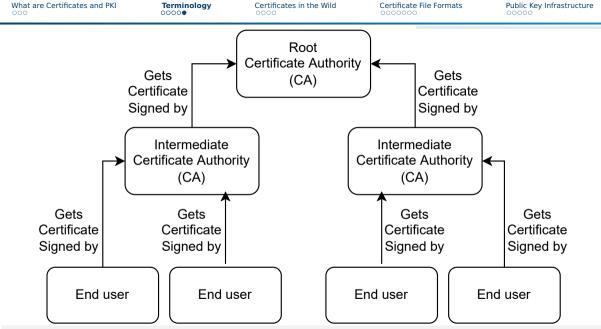
"A user that is registered in a PKI and, therefore, can be named in the "subject" field of a certificate issued by a CA in that PKI."

Public-Key Certificate

- "A digital certificate that binds a system entity's identifier to a public key value, and possibly to additional, secondary data items."
- A public and metadata (hostname, expiry date, etc.)

Root Certificate

- "A certificate for which the subject is a root."
- "The self-signed public-key certificate at the top of a certification hierarchy."



Jonathan Decker

What are Certificates and PKI	Terminology	Certificates in the Wild ●○○○	Certificate File Formats	Public Key Infrastructure

The gwdg.de Certificate

shell

echo | openssl s_client -connect gwdg.de:443 2>/dev/null | \ openssl x509 --text

Public Key Infrastructure

The gwdg.de Certificate

Find from top to bottom:

- Unique Serial Number
- Issuer metadata
- Validity range
- Subject metadata
 - Including encoded public key
- X509v3 extensions
 - Extended Key Usage
 - Basic Constraints
 - CRL Distribution Points
 - Authority Information Access
 - CT Precertificate SCTs
 - Subject Alternative Name
- Signature Algorithm

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	What are Certificates and PKI	Terminology	Certificates in the Wild ○○●○	Certificate File Formats	Public Key Infrastructure
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The hps.vi4io.org Certificate

shell

echo | openssl s_client -connect hps.vi4io.org:443 2>/dev/null|\ openssl x509 --text

Public Key Infrastructure

The hps.vi4io.org Certificate

Find differences top to bottom:

- Issuer metadata
- Validity range
- Subject metadata
- X509v3 extensions
 - CRL Distribution Points
 - Authority Information Access
 - CT Precertificate SCTs
 - Subject Alternative Name

At the end, you will understand most fields

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Certificate Standard: X.509

Most common format

- Separate from SSH and PGP
- From the "PKIX standards"
- Works out-of-the-box for TLS and HTTPS clients and servers
 - Good ecosystem support
- Arose from X.500 project in 1988
 - ITU-T (International Telecommunication Union Standards Body) tried to build a phone book

Certificate Encoding

- X.509 builds on ASN.1. another ITU-T standard
- ASN.1 (Abstract Syntax Notation One) is an encoding standard

Certificates in the Wild

- Similar to ISON and Protobuf
- ASN.1 does not define binary representation
 - Its encoding rules can lead to incompatible binaries
- DER (Distinguished Encoding Rules) is an ASN.1 encoding format
 - Most commonly used for X.509
 - Sometimes also BER (Basic Encoding Rules) another ASN.1 encoding format
 - DER encoding/decoding handled by libraries

https://www.rfc-editor.org/rfc/rfc5280 https://cabforum.org/baseline-requirementsdocuments/

Problematic Standards

- Certificates may be DER format or something "fancier"
 - Raw DER is binary data
- PEM (Privacy Enhanced EMail) encapsulates certificates
 - Adds header and footer
 - May hold any DER certificate, private key, public key
 - Similar to PGP and S/MIME
 - Don't ask why it's called "EMail" that's another 4 RFC document
- PEM headers hold labels to describe payload
 - Attempt at standardization via RFC 7468
 - Labels can be inconsistent
- PEM file "typically" stored as .pem, .crt or .cer
 - Raw DER is commonly stored as .der

Another Layer

- PEM might be included in an "envelope" with additional data
 - A "Certificate" might be a PEM file or an envelope with a PEM
- Envelopes are part of PKCS (Public Key Cryptography Standards)
 - Published by RSA (the company, not the algorithm)
- Most relevant are PKCS#7 and PKCS#12
 - Both can contain certificate chains
 - May hold PEM and raw DER, BER
 - May be stored as raw DER or as PEM
- PKCS#7 was rebranded as CMS (Cryptographic Message Syntax) by the IETF
 - Commonly stored as .p7b or .p7c and used in Java
- PKCS#12 commonly used with Microsoft products
 - Commonly stored as .pfx or .p12

https://www.rfc-editor.org/rfc/rfc3447 https://www.rfc-editor.org/rfc/rfc2315 https://www.rfc-editor.org/rfc/rfc7292

Key Encoding

General pattern:

- ASN.1 data structure
- DER binary encoding
- PEM headers
- Private keys commonly use PKCS#8
 - Can be encrypted using a passphrase
 - Uses another encoding standard within a PEM



hpcsa-course-vm-key.pem was created for your cloud setup by OpenStack
 Try reading it with

shell

openssl x509 --text -noout -in hpcsa-course-vm-key.pem

This fails, its a PEM but not a certificate

shell

openssl rsa -check -in hpcsa-course-vm-key.pem

This prints your RSA private key

Summary

- X.509 is the standard for certificates
- DER is a common encoding used with it
- PEM encapsulates binary DER certificates for better usability on the web
- PKCS#7 and PKCS#12 encapsulate certs with additional certs and data
- Private keys are commonly PEM encoded

Overview

- By definition: Needs no certificates!
- Only goal: Bind names to public keys
 - ~/.ssh/authorized_keys is a PKI
- Web PKI builds on top of certificates
 - Enables secure communication via the internet
- Anyone can create a public key and publish it
 - PGP (Pretty Good Privacy) concept
- On the web, what public keys and certificates to trust?

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Trust Stores

Trust Store contains preconfigured trusted root certificates

- Usually preinstalled in your OS
- Root certificates are self-signed
- Who to trust to pick these?
- Microsoft, Apple, Mozilla (and partially Google) have trust store programs
- Over 100 CAs in most trust stores
 - Not all of them are morally "trustworthy"
 - Some governments operate CAs to spy on their citizens or impersonate websites
 - Some CAs were compromised in the past
- Trust stores are only as secure as the least secure CA

Attack Vector: Headset

2018 Sennheiser headset software installed a root certificate

- Into the trust store of users
- With the belonging private key hidden in the application
- Attackers would extract the private key
 - Use it to sign new web certificates
 - Systems with the Sennheiser software installed would accept them
- This is one example, there are more cases

https://medium.com/asecuritysite-when-bob-metalice/your-headphones-might-break-the-security-ofyour-computer-4f304ed86611

Improvements to Security

- Baseline for issuing CAs was made more strict
- RFC 6962 introduced CT (Certificate Transparency)
 - Impartial observers check for fraudulent certificates
 - Checks are recorded in the certificates
- Root CA certificates are not used for automatically singing certificates
 - Only kept on special air-gaped machines
 - Intermediate certs used for automatic signing (certificate chain)
- Do not disable certificate path validation
 - ▶ e.g., curl -k
 - Unless you know you can trust the server

Public Key Infrastructure

Inspecting Your Trust Store

- On Linux installed via ca-certificates package
- In /etc/ssl/certs
- Extract and inspect certs

```
shell
trust extract --format=x509-directory x509-certs & cd $_
openssl x509 -noout -text -inform=der -in NAME.pem
```

- Look for
 - Issuer
 - Subject
 - Validity
 - x509 extensions

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6 Practical Problems

7 Let's Encrypt

Getting a Certificate from a CA - In Theory

- 1 You create a key pair
- 2 You submit your key with your data to a CA
- 3 CA validates your data
- 4 CA signs and returns a certificate
- After some time your certificate expires
 - Replace it using above process

Practical	Problems
000000	00000

Getting a Certificate from a CA - In Practice

Solve two hard problems in computer science

- Cache invalidation
- Naming things

DNs (Distinguished Names)

Certificate issuer/subject metadata field

- Subject: YOUR_NAME
- YOUR_NAME could be my.domain.de
- Historical artifact
- Instead only use CN (Common Name)
- List domains under SANs (Subject Alternative Names)
 - DNS:my.domain.de
 - Wildcards are possible DNS:*.pages.gwdguser.de
 - Be careful with wildcards

Generating a Key Pair

- Optimally, generate the key pair yourself
- Ensure security of the private key
- From key pair generate a CSR (Certificate Signing Request)
 - CSR is signed, can be freely shared
- Send CSR to a CA

Practical Problems	Let's Encrypt
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Exercise

Certificate Signing Request Validation

CSR Validation has 3 Options:

- DV (Domain Validation)
 - Check DNS name in WHOIS record
 - Either send an email
 - Or use ACME (Automatic Certificate Management Environment)
 - For a HTTP challenge
 - For a DNS TXT record check
- OV (Organization Validation) and EV (Extended Validation)
 - Builds on top of DV
 - Associate legal entity with certificate
 - Takes days or weeks to process
- DV is good enough usually

https://ietf-wg-acme.github.io/acme/draft-ietfacme-acme.html

Domain Validation Security

What does successful DV mean?

Some entity was at one point in time able to either

- Read email
- Configure DNS
- Serve an HTTP challenge
- Relies on the security of these layers
- Fraudulent certificates were issued
 - e.g., on an Amazon domain in 2018

https://doublepulsar.com/hijack-of-amazonsinternet-domain-service-used-to-reroute-webtraffic-for-two-hours-unnoticed-3a6f0dda6a6f

Certificate Expiration

- Validity range on certs is very common
- Not a hard requirement
- Incorrect system clocks are a problem
 - Out of sync system clock might reject a valid cert
 - Systems without internal time reset to UNIX epoch 0 or 01.01.1970
- Private keys should have proper life cycle
 - Separate keys for certificate singing and encryption

Certificate Renewal

- No standard process
- Just replace the old cert with a new one
- Short lived certs are better for security
- Let's Encrypt defaults to 90 days

Certificate Revocation

- Certs might be unneeded
- Private keys can be compromised
- \Rightarrow Revoke the certificate
- Revoking X.509 certs is a mess
- Revocation status cannot be encoded in a certificate
- 2 systems in use
 - CRLs (Certificate Revocation Lists)
 - OCSP (Online Certificate Singing Protocol)

CRLs (Certificate Revocation Lists)

Defined in RFC 5280

- Long list of serial numbers of revoked certs
- Can be linked in a certificate
 - "Look for my serial number here, if I am on this list, I am revoked"
- What if the CRL endpoint is unreachable?
 - The certificate is accepted
- Lists are often cached
 - Propagating new revocations takes time

OCSP (Online Certificate Signing Protocol)

- Defined in RFC 2560
- Similar to CRL, endpoints can be queried for status of a cert
- Queries are for a specific certificate
- Privacy issue: The OCSP responder knows the websites you are visiting
- Solved by OCSP stapling
 - Owner of cert gets short-lived token from OCSP to validate cert
 - Might as well use short-lived certificates

https://www.ietf.org/rfc/rfc2560

Using a Certificate

- 1 Set up a HTTPs server
- 2 Point it to certificate file and public key
- 3 Done

Overview

Non-profit company

- https://letsencrypt.org/
- Founded in 2012
- Provides a free service for acquiring certificates
 - Only supports automatic domain-validation
 - Over 300 mil (unexpired) certificates November 2022

Certbot

Open-source tool

- Allows obtaining certificates from Let's Encrypt
- Can also install them via plugins
 - Support Apache, NGINX, etc.
- Automatically renew certificates
- Uses ACME for DV

Exercise

Please work on the exercise now.