

# Standard Security Protocols

*Going up the stack:*

*PKI, DNS, TLS, IPsec and all that*

# Next hour(s)...

- PKI model and protocols
  - SMIME formats and (a bit on) email
  - **TLS protocol (TLS1.2 or TLS1.3)**
  - IPsec
  - Kerberos
  - SSH
  - Wireguard
- Knowing **one** of these in detail is enough for exam purposes – you **will** need to read the source materials

# First bit...

- Yawning :-)
- Why standards?
- Standards Development Organisations (aka alphabet soup)
- Couple of examples
- When to standardise?

# Why standardise?

- Generic reasons:
  - Multi-Vendor Interoperability
  - “Open”-ness
- Security Reasons
  - Remember: Crypto => Interop is hard!
  - Review: Many (non-security) standards decrease security
- NB: Not everything needs to be standardised!

# A Possibly New Why?

- Human Rights Protocol Considerations Research Group
  - <https://irtf.org/hrpc>
- “Rethinking Privacy Online and Human Rights: The Internet’s Standardisation Bodies as the Guardians of Privacy Online in the Face of Mass Surveillance”
  - Adamantia Rachovitsa, Conference Paper No.5/2016 2016 ESIL Research Forum, Istanbul, 21-22 April 2016 (see materials page for copy and link to original)

# Standards Development Organisations (SDOs)

- International organisations
  - e.g.: UN/ITU, ISO
- "Open" Internet Standards Development Organisations
  - e.g.: IEEE, IETF, W3C
- Commercial Enterprise Driven SDOs
  - e.g.: OASIS, FIDO Alliance
- Company-specific pet projects
  - e.g.: FB Free basics/internet.org
- Open-source projects
  - e.g.: Apache, WHATWG, OpenSSL, ...
- Open-source commercial alliances
  - e.g.: OpenStack
- Operational entities:
  - e.g. ICANN, RIPE, ARIN,...
- Topic specific alliances
  - e.g. M3AAWG, Lora alliance, ...

# Types of standards

SDOs produce different categories of output, not all standards, e.g. RFC1149

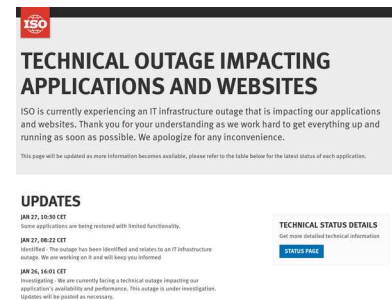
- Draft versions may be published or not, long-lived or not, rubbish or not

Almost all interesting standards in this space are openly available - some for a fee!

But note: All SDOs have some business model, even the best/most-open ones

# ISO/ITU-T

- National bodies are members (NIST, Enterprise-Ireland)
  - <https://www.iso.org>
  - <https://www.itu.int>
- Security stuff:
  - Child online protection (ITU?)
  - Cryptographic mechanisms (ISO)
  - Even more X.509 (PKI stuff ITU-T, mostly useless/irritating)
  - Various ITU telephony specs
    - Some inheriting from/profiling IETF





# Internet Engineering Task Force (IETF)

- No members: (in theory) a group of individuals developing the Internet

<https://www.ietf.org> <https://www.irtf.org>

- Security:
  - About 1-2 dozen of about 100 working groups usually doing interesting security stuff
- Best of a bad lot really!
  - But I would say that having been involved with this lot for >25 years;-)

# World-Wide-Web Consortium (W3C)

- Membership organisation (\$5-50k per annum) plus strong “team” plus invited experts

<https://www.w3.org>

- Some interesting old security groups
  - XML Sig, Enc, XKMS
- Currently:
  - WebRTC
  - Focus more on browser APIs and not protocols
  - Privacy Interest group being more active

<https://www.w3.org/blog/2022/01/privacy-interest-group-ping-2021-year-in-review-and-thank-yous/>

See also: WHATWG <https://whatwg.org/>

# IEEE Standards Association

- Individual memberships but meeting attendance counts

<https://www.ieee.org/>

- Security:
  - IEEE 802 – various security things, WPA etc.
  - MAC address randomisation,
  - MACsec (layer 2 crypto)

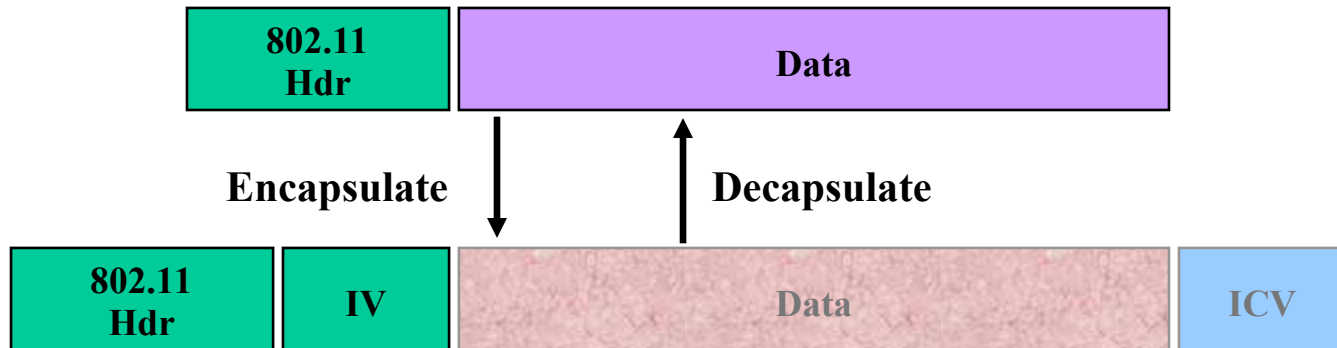
# Examples of “standards”

- Really good: RFC822/2822/5322 – Mail message format
- Middling: RFC3185 “Re-use of CMS Content Encryption Keys”
  - (Ahem!) Co-author present :-)
  - Length: 10pp (-crud=3pp)
  - Duration: ~18 months
  - Purpose: Fix a problem for RADIUS/Diameter
  - BUT: Zero implementations

# “Bad” examples

- Many to choose from
- IETF: IKEv1 (see later)
- IEEE: WEP (or was it?)
  - [https://www.ieee802.org/11/Documents/DocumentArchives/1994\\_docs/194249\\_scan.pdf](https://www.ieee802.org/11/Documents/DocumentArchives/1994_docs/194249_scan.pdf)  
version 1.0 November 1994

# WEP Encapsulation

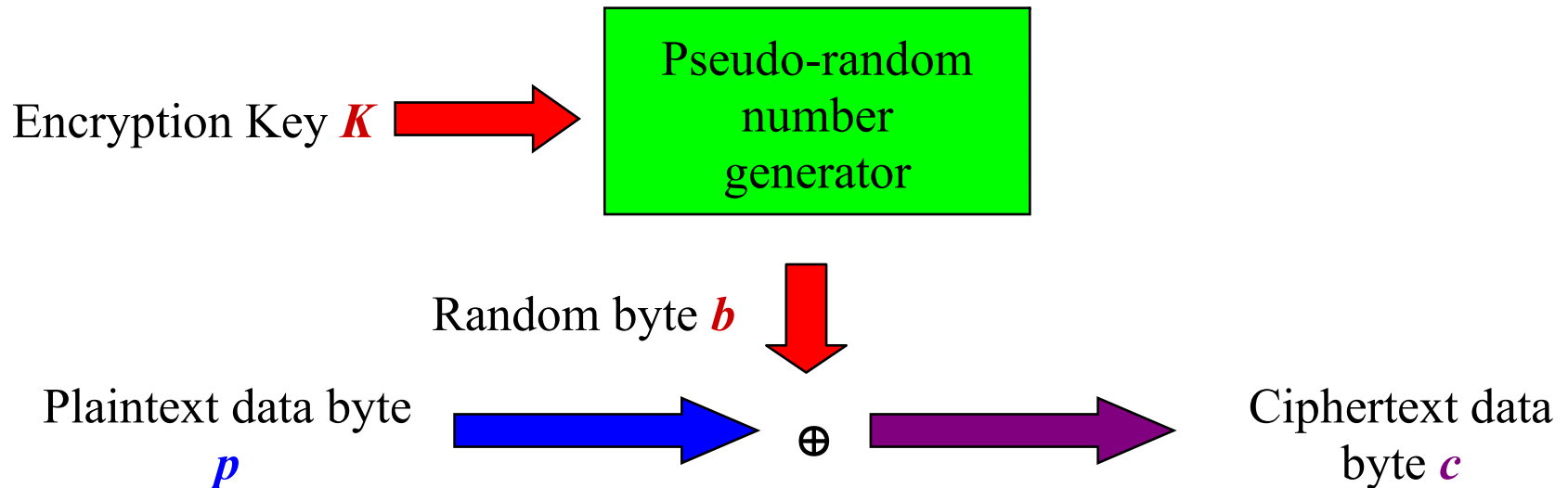


## WEP Encapsulation Summary:

- Encryption Algorithm = RC4
- Per-packet encryption key = 24-bit IV concatenated to a pre-shared key
- WEP allows IV to be reused with any frame
- Data integrity provided by CRC-32 of the plaintext data (the “ICV”)
- Data and ICV are encrypted under the per-packet encryption key

# Properties of Vernam Ciphers (1)

The WEP encryption algorithm RC4 is a Vernam Cipher:



Decryption works the same way:  $p = c \oplus b$

# Properties of Vernam Ciphers (2)

*Thought experiment 1:* what happens when  $p_1$  and  $p'_2$  are encrypted under the same “random” byte  $b$ ?

$$c'_1 = p'_1 \oplus b$$

$$c_2 = p_2 \oplus b$$

Then:

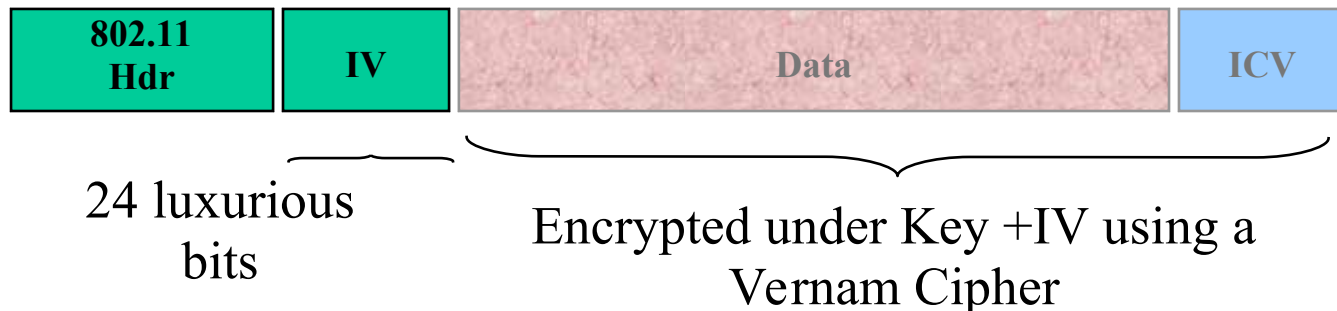
$$c'_1 \oplus c_2 = (p'_1 \oplus b) \oplus (p_2 \oplus b) = p'_1 \oplus p_2$$

**Conclusion:** it is a very bad idea to encrypt any two bytes of data using the same byte output by a Vernam Cipher PRNG.

*Ever.*



# How to Read WEP Encrypted Traffic (1)



- By the Birthday Paradox, probability  $P_n$  two packets will share same IV after  $n$  packets is  $P_2 = 1/2^{24}$  after two frames and

$$P_n = P_{n-1} + (n-1)(1-P_{n-1})/ 2^{24} \text{ for } n > 2.$$

- 50% chance of a collision exists already after only 4823 packets!!!
- Pattern recognition can disentangle the XOR'd recovered plaintext.
- Recovered ICV can tell you when you've disentangled plaintext correctly.
- After only a few hours of observation, you can recover all  $2^{24}$  key streams.

# How to Read WEP Encrypted Traffic (2)

- Accelerate the process!
- Send spam into the network: no pattern recognition required!
- Get the victim to send e-mail to you
  - The AP creates the plaintext for you!
- Decrypt packets from one Station to another via an Access Point
  - If you know the plaintext on one leg of the journey, you can recover the key stream immediately on the other
- Etc., etc., etc.

# Question

- WEP was broken after being deployed, and then fixed. Same is true of SSL which became TLS.
- Was that better or worse than IPsec/IKE that took 10 years to develop?

# When to standardise

- When many implementer's codebases have to talk a protocol
  - HTTP, SMTP,... (many, many examples)
- When one implementer has to use another vendor's API
  - WebRTC, PKCS#11
- When serious review is required
  - Routing (BGP) or TCP changes like RED, AQM
  - Crypto algs, e.g. AES, PQ algs

# When not to...

- When you just want your name in “lights”
- When your clever algorithm is the tenth way to do the job
- When your scheme is patented
  - Or secretly about to be patented!
- When no-one cares
- See RFC 6417 for guidance for researchers

# More on when not to...

- If you're an open-source team and don't have the cycles to engage with all the axe-grinders who'll get involved when you engage in a really open process (and they will) - e.g. Tor
- If you claim that implementation agility and speed is more important than multi-implementer interop - e.g. Signal, maybe wireguard

# Standard Security Structures and Protocols

*PKI, S/MIME, SSL, Kerberos, IPsec, SSH, Wireguard*

*Basically, things that do automated key management and  
secure application data transport*

# Materials

- Lots of RFCs
- <https://datatracker.ietf.org/wg/Bleichenbacher/> "Avoiding the million-message attack" RFC 3218
  - Good one for those who want to read ahead...



# Next hour(s)...

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# Public Key Infrastructure (PKI)

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- Key management is a scaling problem
- Possible to push “trust” (bad term!) up to a certification authority (CA)
- “Trust” here is: CA is responsible for binding information about an entity (esp. names) with a public key
  - Anyone who trusts that CA for that purpose can then check that entity's signature or encrypt to it

# PKI History

- Original concept: publishing public keys in newspapers
- Electronic equivalent suggested in 1978 undergrad work:
  - Kohnfelder, "Toward a practical public key cryptosystem," Bachelors Thesis, MIT Dept. of Electrical Engineering, May 1978  
<https://dspace.mit.edu/handle/1721.1/15993>
- First standard was X.509 in 1988
- IETF X.509 profile is in **RFC 5280** from 2008, used by TLS, S/MIME and lots of other protocols

# X.509-based PKI Problems

- Everyone sensible has disliked X.509 since about the late 1990's
  - It's old, gnarly & horrible
- Every now and then someone suggests replacing it with <foo>
  - Sadly, so far, no <foo> has been sufficiently better to **displace** X.509 based PKI
- Maybe in 5-10 years it'll be less important, but for now we have to suffer

# Certificates (1)

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

- Who knows what ASN.1 is?
  - An **A**bstract **S**yntax **N**otation
  - With tag, length value encoding schemes (BER, DER, PER)
    - SEQUENCE -> 0x30, INTEGER -> 0x02
  - PITA, as are all marshalling schemes in the end

# Certificates (2)

```
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,  
    subjectUniqueID   [2] IMPLICIT UniqueIdentifier OPTIONAL,  
        -- If present, version MUST be v2 or v3  
    extensions        [3] EXPLICIT Extensions OPTIONAL  
        -- If present, version MUST be v3  
}
```

# Certificate Revocation Lists

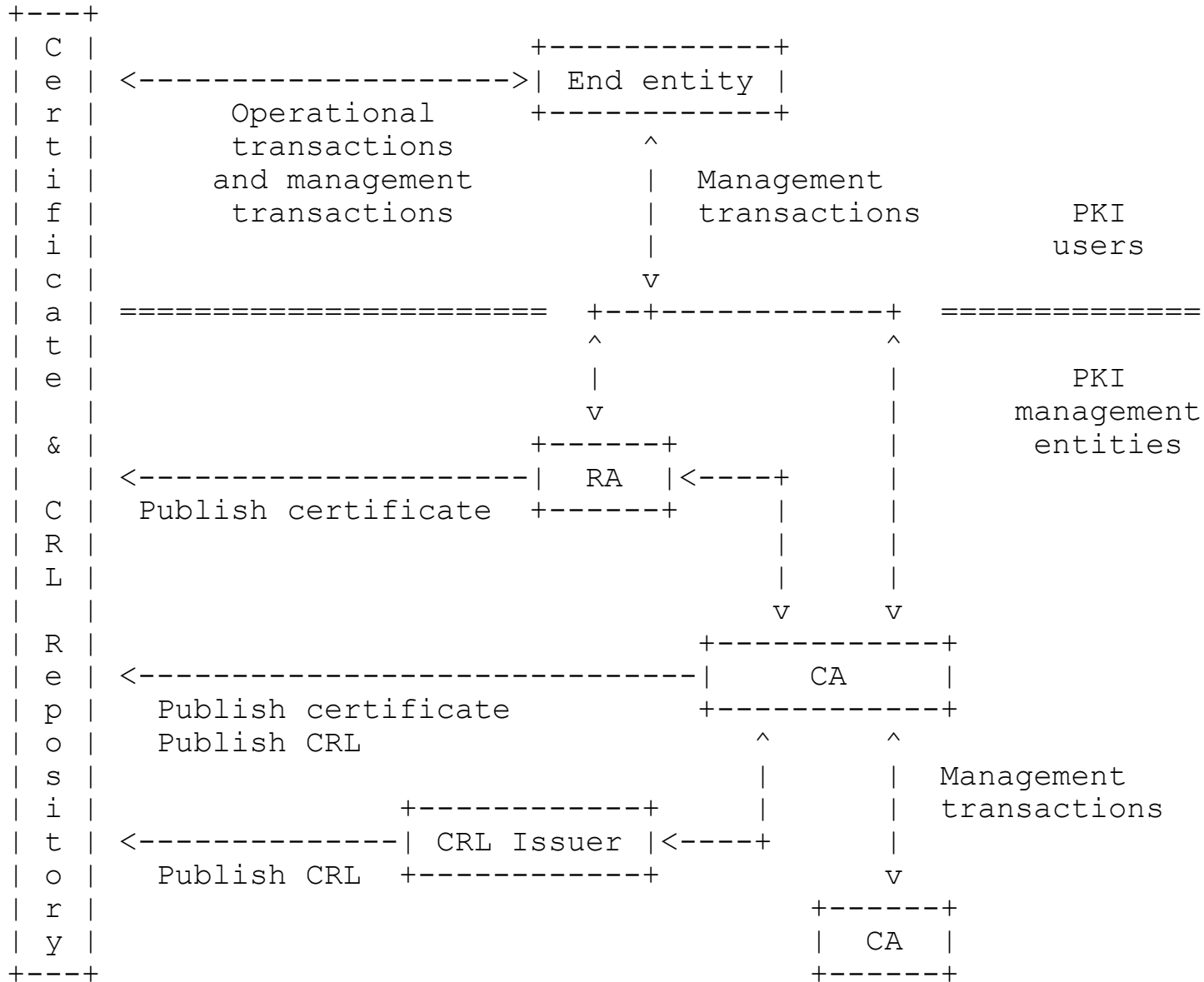
- A list of "bad" certificate serial numbers (plus list-entry-extensions)
- Periodically issued by a CA
- Revocation = putting on block-list
- Revocation information can also be fetched via on-line certificate status protocol (OCSP)
- OCSP-responses can be stapled
- Reasons to revoke: Key compromise, Key loss, Change of function, Uninstall web server...



# To check a certificate

- Start with a (set of) locally trusted CA public keys
- Progress down certification path:
  - Is next-signature ok with previous public?
  - Is certificate revoked?
  - Continue
- Missing lots (see rfc5280)
  - E.g. Policy mappings (yuk), but do ignore those!

# PKI Entities



# PKI Protocols

- Registration & renewal: PKCS#10, proprietary, CMP, CMC, EST and now **ACME**
  - CMP (RFC 4210) still used by 3gpp, and for trains!
- Certificate retrieval: **in-band**, LDAP, DAP, HTTP, FTP, DPD
- Certificate status checking: **OCSP**, DPV, CRL processing, and now (maybe) application specifics like CRLite
  - <https://blog.mozilla.org/security/2020/01/21/crlite-part-3-speeding-up-secure-browsing/>
  - Browsers perhaps only caring about CA and popular-domain revocations these days, not sure
- Certificate Transparency (**CT**) for logging certificate issuance has been a success

# Roots/Trust Points

- Applications using PKI need to have a local set of (root) CA public keys they “trust”
- Browsers and OSes have those – each with hundreds of CA organisations in the list
- In/ex-clusion is highly political
  - <https://cabforum.org/> is a venue for some of that
  - Mozilla operate a public discussion list (other tend to be less public)  
<https://groups.google.com/a/mozilla.org/g/dev-security-policy>
- The WebPKI is a special case today – biggest and most important PKI but quite a few others do exist
  - Other applications and OSes handle things similarly, often with some overlap with WebPKI

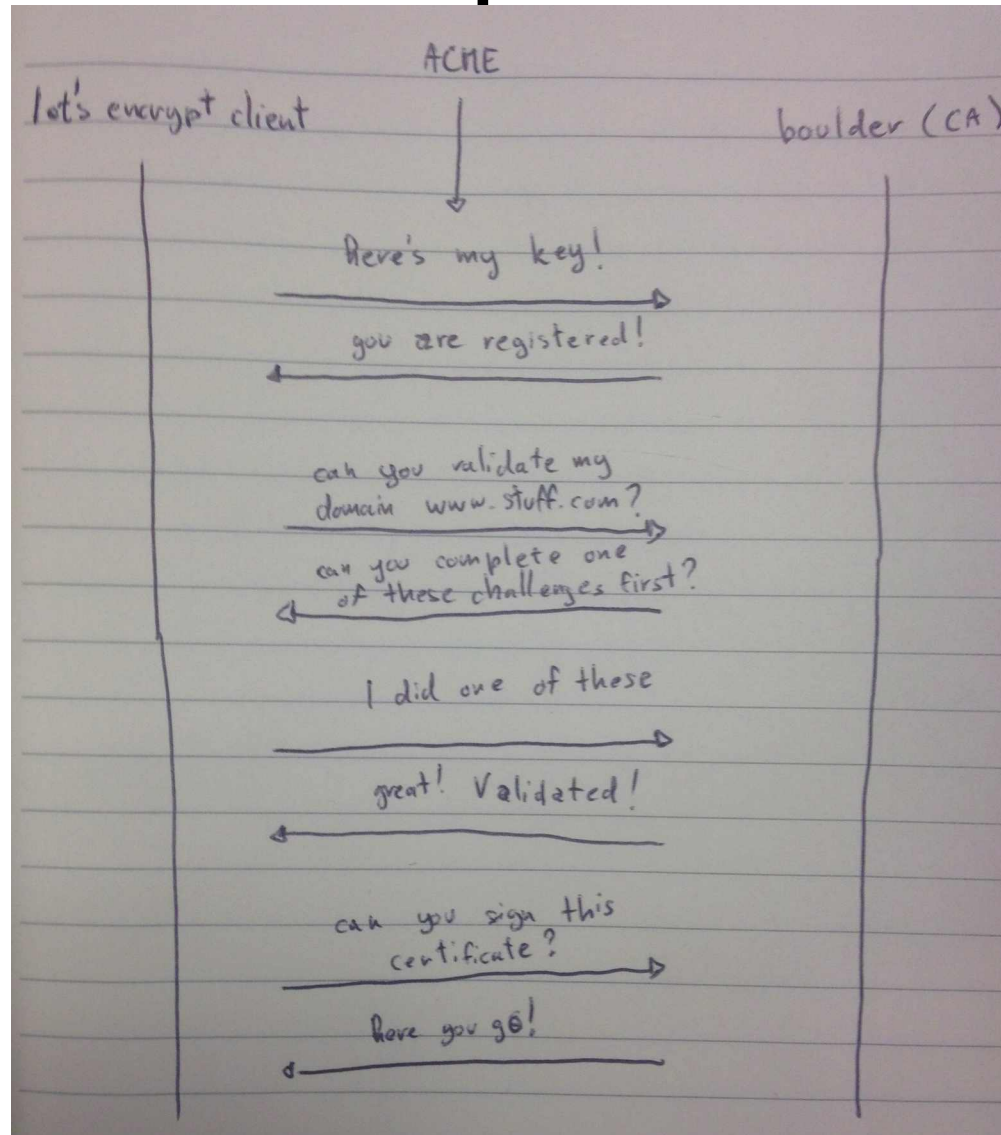
# Some good news though...

- <https://letsencrypt.org/> operating a free CA since Dec 2015
- ACME protocol for automated certificate management
  - JSON based
  - RFC 8555

# ACME protocol

- Automated Certificate Management Environment (ACME) is an HTTP-based protocol for managing certificates
  - Works with LE and other CAs for acquiring Domain Validated (DV) certificates
  - RFC 8555
- Quite a few client implementations:
  - Certbot, ACME.sh, ...
- Typically: command line registration then (~weekly) cron job for renewal

# ACME protocol



# ACME protocol

- ACME challenges:
  - Evidence for domain validation
  - There's a history of these turning out tricky in some deployment scenarios
- Challenge types:
  - http-01: random content at e.g.  
“/.well-known/acme-challenges/abcdef0123456”
  - dns-01: As above but in DNS
  - tls-sni-01/02: deprecated! Demonstrate ability to use random TLS SNI value



# Certificate Transparency (CT)

- There have been cases where CA's have been hacked or misbehave (more later)
- CT improves the WebPKI
  - CT specified in (non-standard) RFC 6962 in 2013
  - Standardisation process hugely sloooow.... Version 2.0 is defined in RFC 9162 (2021)
  - I suspect everyone may stick with RFC 6962
- Idea: append-only public logs of all certificates issued to allow detection of mis-issuance (not prevention, detection!)
- Nice (if not quite reliable) search UI: <https://crt.sh/>
  - Reminder to self: pop up this URL and show stuff: <https://crt.sh/?q=tcd.ie>

# Attribute certificates

- RFC5755 - Certificate-like thing with generic attributes (e.g. group membership) and no subjectPublicKey
- Treat as experimental if you ever hear about them
- Can be used for role-based access control etc.
- BUT... when these seem useful there's almost always a better way!

# PQ certificates

- New PQ algs will require public keys in certificates, which is fine (e.g. Dilithium, Kyber public keys)
- Some people are proposing ways to embed two public keys in one certificate to support use of hybrid protocols
  - That could end up a disaster, but we'll see
- A bunch of documents are visible at:  
<https://datatracker.ietf.org/wg/lamps/documents/>

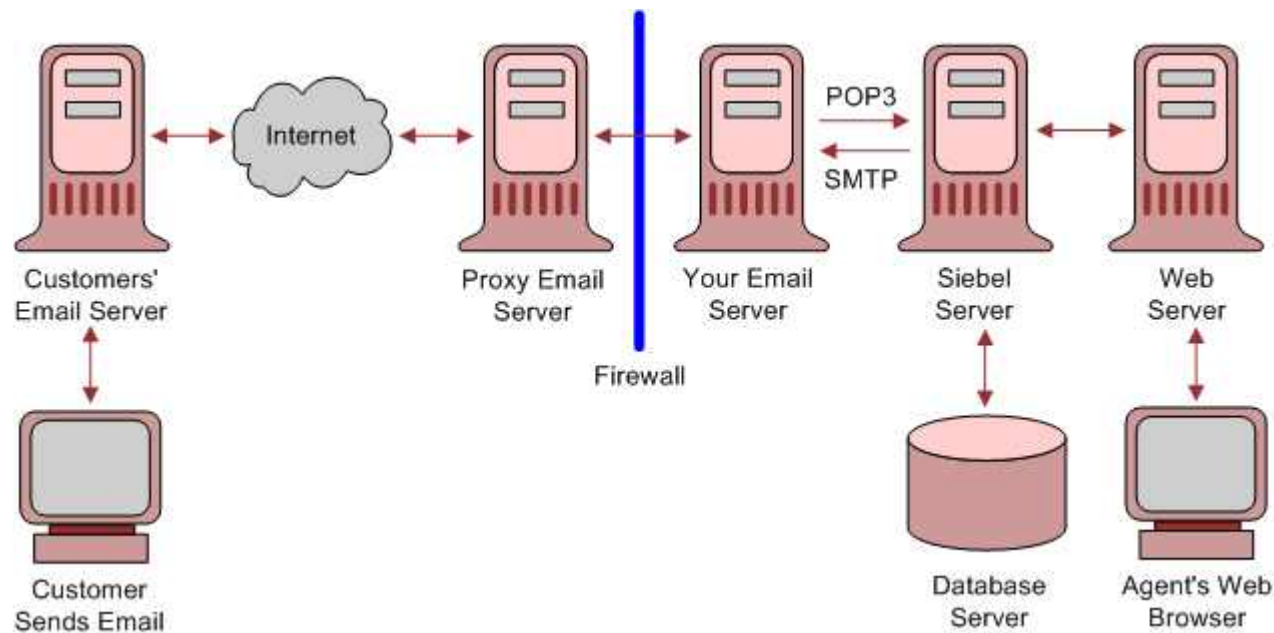
# X.509-based PKI Summary

- Mix of mature and new(ish) technology
  - Plenty of open-source, products and services and significant deployment experience
- Deployment and application integration problems will always exist
  - Can be overcome but expensive
- Still technology-of-choice for scalable public key management
- Improvement is possible: e.g. ACME/CT
- Might be affected by post-quantum crypto
  - Or, hopefully PQC will tip us into finally moving to something better

e-Mail, spam, S/MIME and PGP

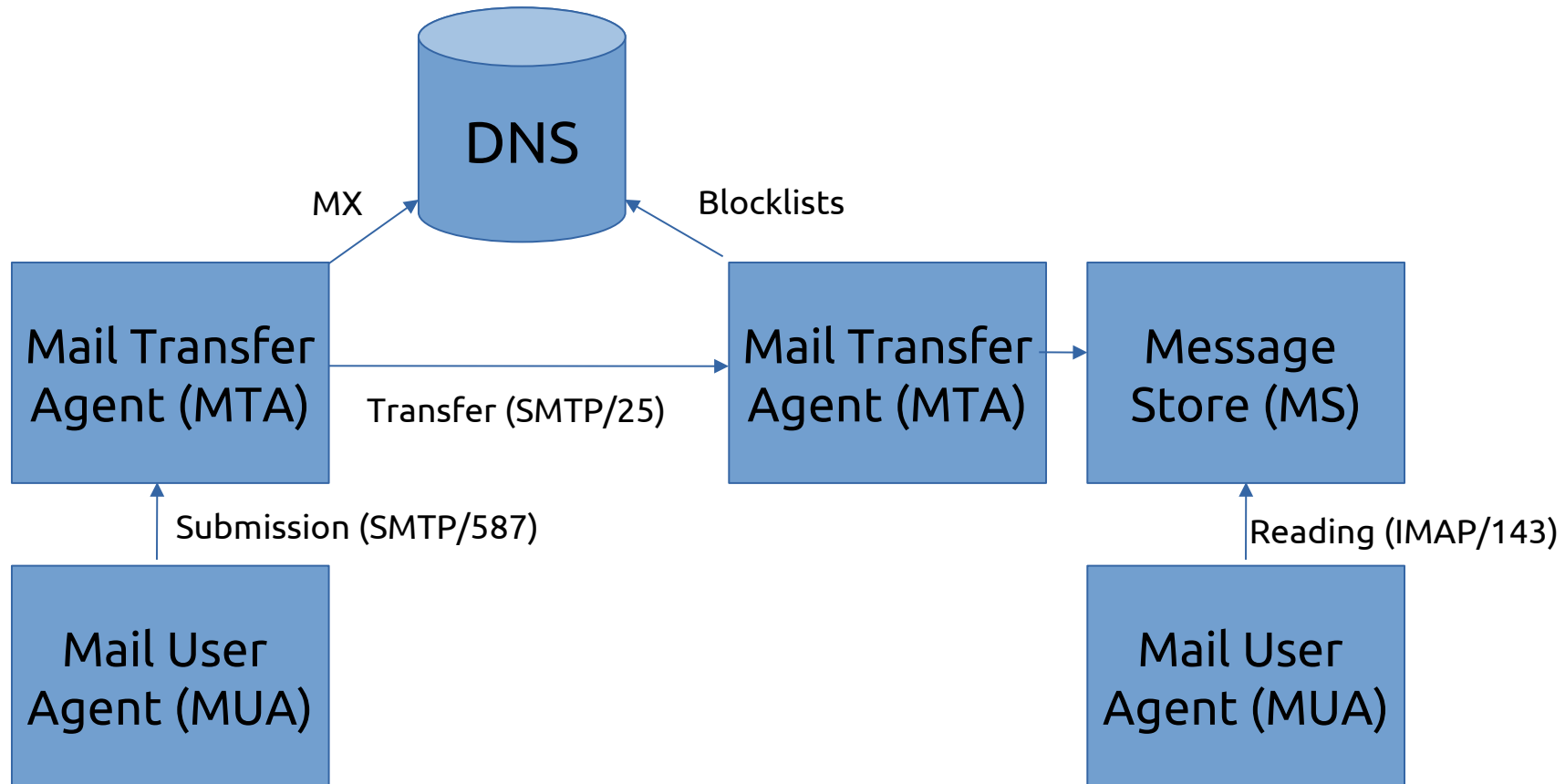
# Email Architecture

- See RFC 5598

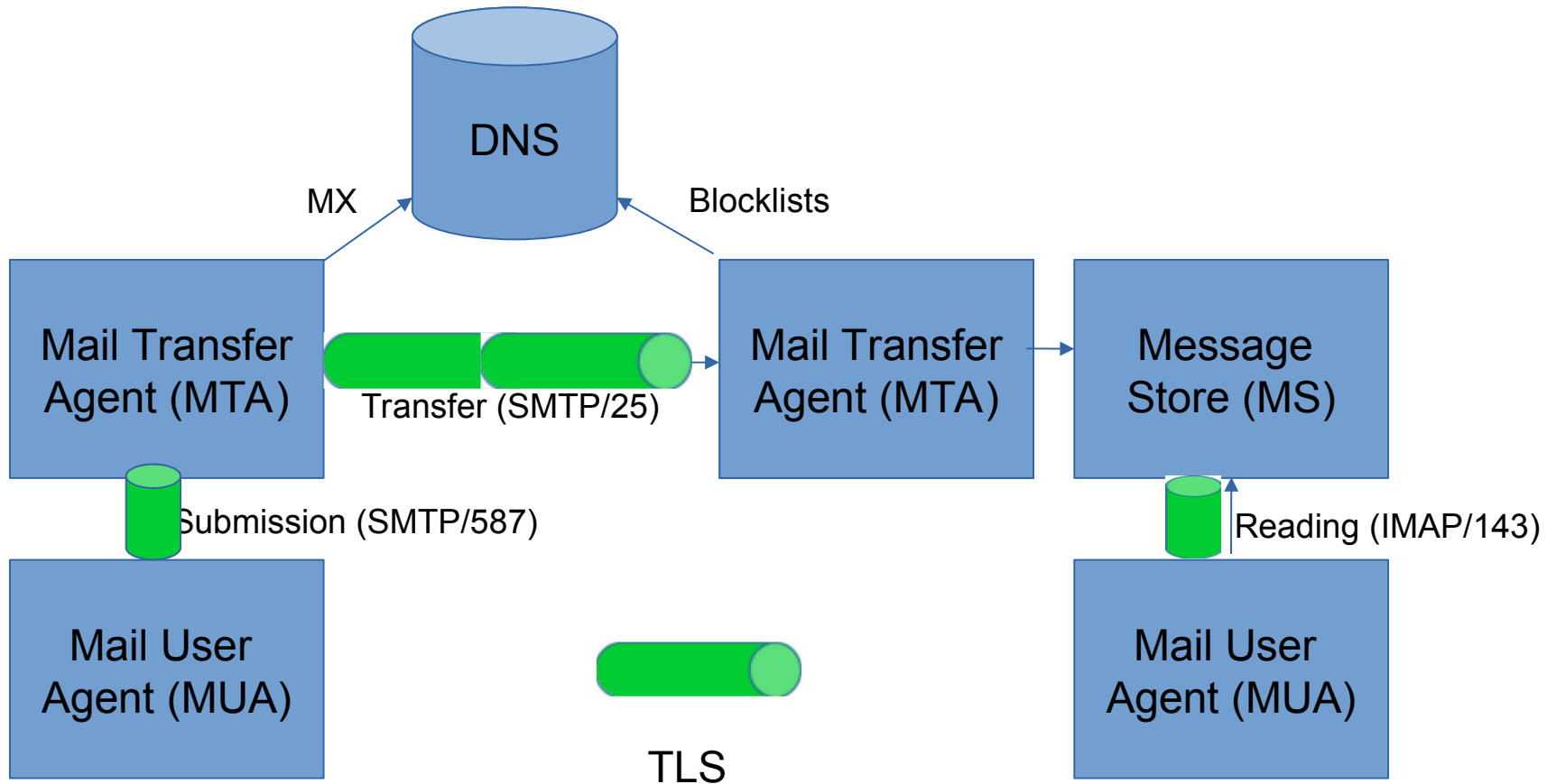


[https://docs.oracle.com/cd/E63029\\_01/books/SecurHarden/img/architecture\\_email\\_v.gif](https://docs.oracle.com/cd/E63029_01/books/SecurHarden/img/architecture_email_v.gif)

# Another architectural view



# Mail Transport Security



Mail Transport Security sometimes described as “hop-by-hop security”



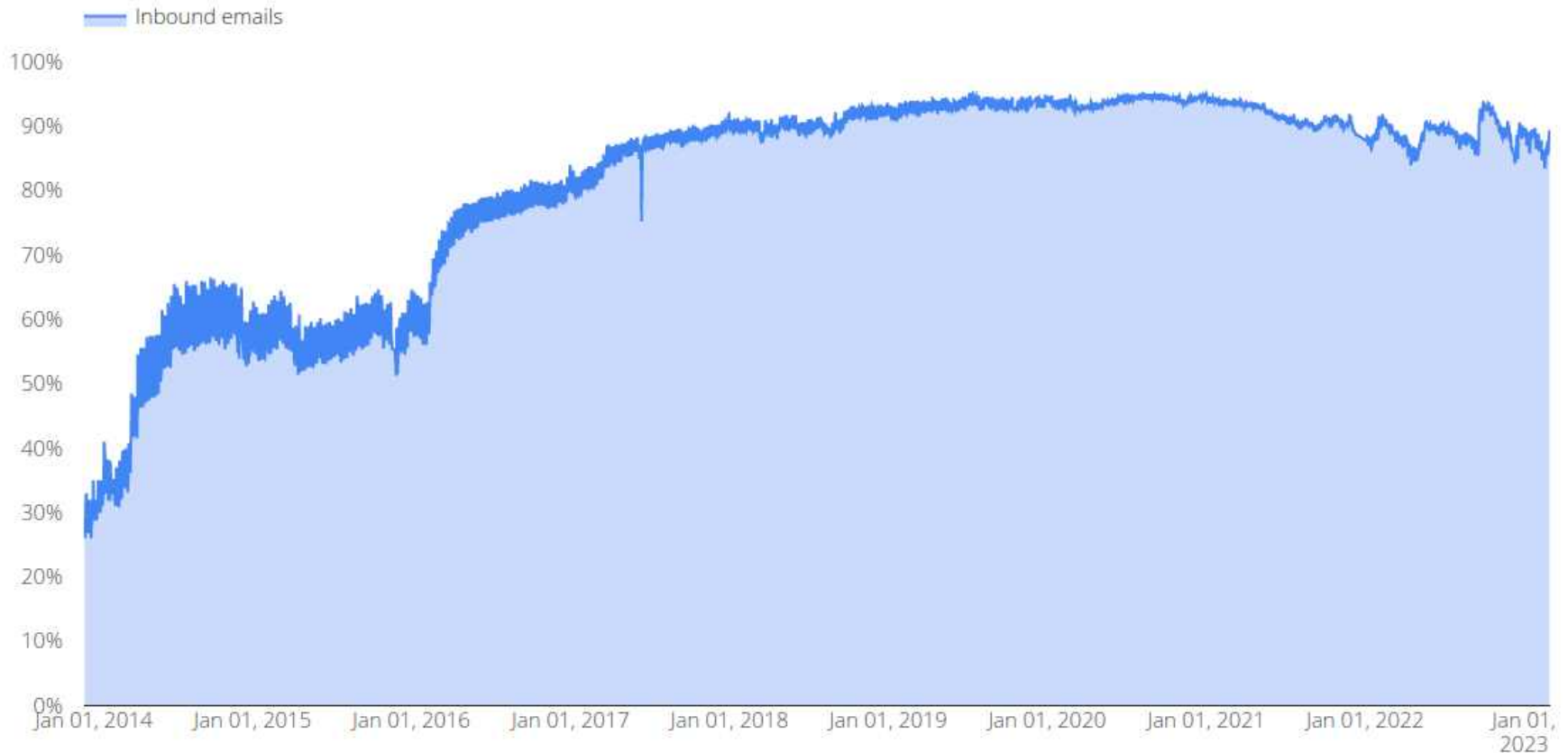
# Mail Transport Security Stats

- Gmail publish “transparency report” stats
  - <https://transparencyreport.google.com/safer-email/overview>
- Other service providers see commensurate numbers
- Recently: 91% of outbound and 89% of inbound are protected via some form of TLS
  - Note: “Some form” == possibly opportunistic!
- That 89% used to be 93%, not clear why graph getting noisy
- Regional variations remain

# HBH over time (still @gmail)

Inbound email encryption: 89%

Start 📅 3/6/2013      End 📅 3/6/2023



# Opportunistic SMTP/TLS (1)

- Sending MTA looks up MX RR of recipient's DNS domain
- MX name might not be same as recipient's domain, e.g., tcd.ie's MX is msft/outlook
- Sending MTA is TLS client, receiving MTA is TLS server
- Question: which name to require in TLS server cert? MX name or recipient domain?
- Answer: many receiving domains outsource MX to someone big and good at anti-spam meaning sending MTA has to deal with MX names and can't insist MX be able to serve TLS certificate of recipient domain

# Opportunistic SMTP/TLS (2)

- Today many MX's still serve self-signed certificates or expired certificates or certificates signed by some CA not trusted by sending MTA (e.g. a corporate CA)
- For all the above reasons, SMTP/TLS is often still “opportunistic” in that MTAs enable it, but don't impose the same level of checks as are done on the web
- Note: on the web, there's often a warm body who can see/react to errors or warnings – there is no human user present when a sending MTA tries to establish SMTP/TLS with a receiving MTA

# MTA-STS

- To improve on opportunistic SMTP/TLS we need receiving MTAs to publish a signal that it's ok for sending MTAs to be more strict
- MTA Strict Transport Security (RFC 8461) defines a way to publish that information in the DNS (so sending MTA can look for it before starting to connect)
  - Modelled on HSTS and DKIM
- Important: has a “testing” phase and defines how sending MTAs can report stats occasionally

# Mail and SPAM

*...just can't seem to get enough...*



<https://www.theguardian.com/environment/2017/feb/13/extraordinary-levels-of-toxic-pollution-found-in-10km-deep-mariana-trench#img-1>

# What is spam?

- Various acronyms:
  - Unsolicited bulk email (UBE)
  - Unsolicited commercial email (UCE)
- Spam is bad:
  - Resource consumption
    - Filters, scanners etc. cost time & money
  - Malware
  - Phishing attempts

# Sometimes hard to know...

HILARY TERM GREETINGS FROM THE  
COLLEGE CHAPLAINS The College  
Chaplains send best wishes to all, and would  
like to bring the following upcoming events to  
your attention. They are open to any students  
or staff members who wish to join us. ...



# Original spam tricks

- Just send email!
  - Ahh...the naivety of it all!
- Email to list
  - Listservers got better, e.g. subscriber only with controlled subscription
- Forge headers
- Send via open relay
  - Used to be a lot of these, very few now
    - toad.com is (or was) an exception!

# More spam tricks...

- Confusion:
  - accounts@paypal.com
  - [support@eboy.com](mailto:support@eboy.com)
  - [postmaster@boi-support.com](mailto:postmaster@boi-support.com)
  - About to get worse thanks to I18N
  - security@bigbank.com
    - ^ Unicode 0430 is cryllic small ‘a’
- Throwaway domains/addresses
- Zombie’d hosts
- BGP spoofing
- DKIM replay

# Yet more

- HTML messing
  - Colour-related
  - Relay sites
  - Encoded URIs
  - Font size 0: break words with zero width spaces

# How much spam is there?

- Lots
  - Hard to get good figures, these are ones I've overheard
- ISP backbones:
  - 70% + of email traffic
- Delivered mail:
  - 40% + delivered
- Increasing or not?
  - Harder to tell if MTAs silently filter

# How to solve spam...

- Over to you...
- But beware of FUSSP
  - <https://www.dmath.org/fussp/>

# Recent Anti-spam techniques

- Content filtering (Bayesian, etc.)
  - Misc. AI magic
- DNS Block Lists (SORBS, DNSBL)
- Register of known spam operators (ROKSO)
- Greylisting
  - All in widespread use today
- Sender Policy Framework (SPF)
- Domain Keys Identified Mail (DKIM)
- DMARC

# SPF, DKIM, DMARC (v. briefly)

- Sender Policy Framework (SPF): publish IP addresses of sending MTA in DNS; receiving MTA checks source IP of inbound connections – RFC 7208
- Domain Keys Identified Mail (DKIM): sending MTA digitally signs outbound emails with private key associated to sending domain; receiving MTA looks up public key in DNS and checks signature; missing/bad signature treated as unsigned message - RFC 6376
- Domain-based Message Authentication, Reporting, and Conformance (DMARC): sending MTA publishes “policy” in DNS stating how it would like receiving MTAs to treat messages, e.g. requiring SPF and DKIM to “pass” before accepting email, up to and including asking receivers to “reject” inbound mail that fails SPF or DKIM – RFC 7489

# DMARC Downsides (1)

- DMARC is great for transactional mail (e.g. receipts), but, there are valid and (to some) important uses of 3<sup>rd</sup> party sending: Mailing lists, alumni addresses
- Mailing lists are the main tool for discussing how Internet standards (incl. Mail, incl. DKIM, incl. DMARC) should work, so breaking those seems dim
- But some mail service providers will prefer to reduce their costs even so
  - <https://www.pcworld.com/article/2141120/yahoo-email-antispooing-policy-breaks-mailing-lists.html>
  - [https://wiki.asrg.sp.am/wiki/Mitigating\\_DMARC\\_damage\\_to\\_third\\_party\\_mail](https://wiki.asrg.sp.am/wiki/Mitigating_DMARC_damage_to_third_party_mail)



# DMARC Downsides (2)

- When sender to mailing list is from a domain that publishes “p=reject” policy, other list-recipients may bounce the mail, leading to non-delivery, but also, after a few such bounces, leading the mailing list to unsubscribe the sender
  - Result: <user>@yahoo.com can no longer participate in e.g. IETF
- Risk: If gmail.com published “p=reject” that would likely cause havoc for organisations that depend on mailing lists
  - Google said they won’t until the impact of that would be reduced sufficiently
- Workarounds
  - Use gmail or a vanity sending domain you control
  - IETF mailing lists re-write sender’s address, e.g. to [first.last=40example.com@dmARC.ietf.org](mailto:first.last=40example.com@dmARC.ietf.org)
- “Solution” for DMARC downsides (ARC) involves DKIM signing by sender’s MTA and a 2<sup>nd</sup> DKIM(-like) signature from list agent, but is complex, and interpreting ARC protections on a message is even more complex so not clear if ARC deployment will help
  - Authenticated Received Chain (ARC) is RFC 8617

# DKIM vs DNSSEC

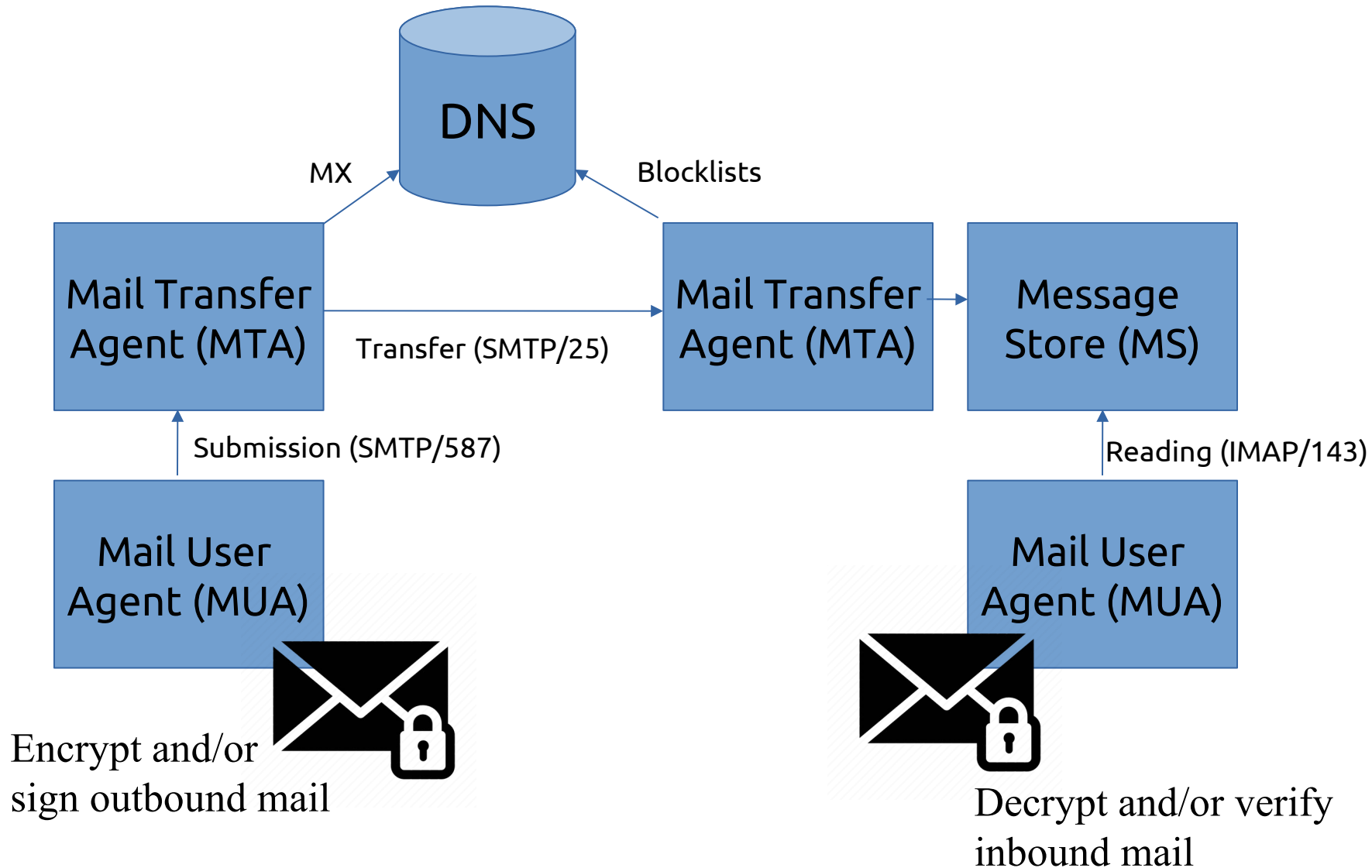
- We're jumping miles ahead here, but will return to this: DKIM and DNSSEC involve publishing public keys in DNS
- DNSSEC DS requires talking to parent domain, chains up to signed root zone
  - ~1% deployment
- DKIM publishes public key in DNS in TXT record with no additional DNS security
  - Today DKIM is almost mandatory if you want your email delivered
  - Partly, that's due to the power of the major mail service providers
- Think about the deployment pros and cons?

# SPAM summary

- Email is historically and still currently a very important Internet application
- Hop-by-hop/transport security for mail has significantly improved since 2013
- SPF, DKIM and DMARC are deployable and very widely used
- DMARC is good for some but not all
- None of the above “solves” spam
- Spam/Anti-spam is an arms-race, beware the FUSSP!

[http://www.circleid.com/posts/20131226\\_the\\_naive\\_arrogance\\_of\\_fussps/](http://www.circleid.com/posts/20131226_the_naive_arrogance_of_fussps/)

# End-to-end (E2E) Email Security



# E2E mail security: S/MIME

- There's a history here too!
  - PGP, PEM and MOSS
  - RSADSI's PKCS#7 based proposal
- Cryptographic Message Syntax (CMS) is the basis for S/MIME and various other crypto applications using ASN.1
  - So S/MIME = CMS
    - + Message-Specification
    - + Certificate-specification

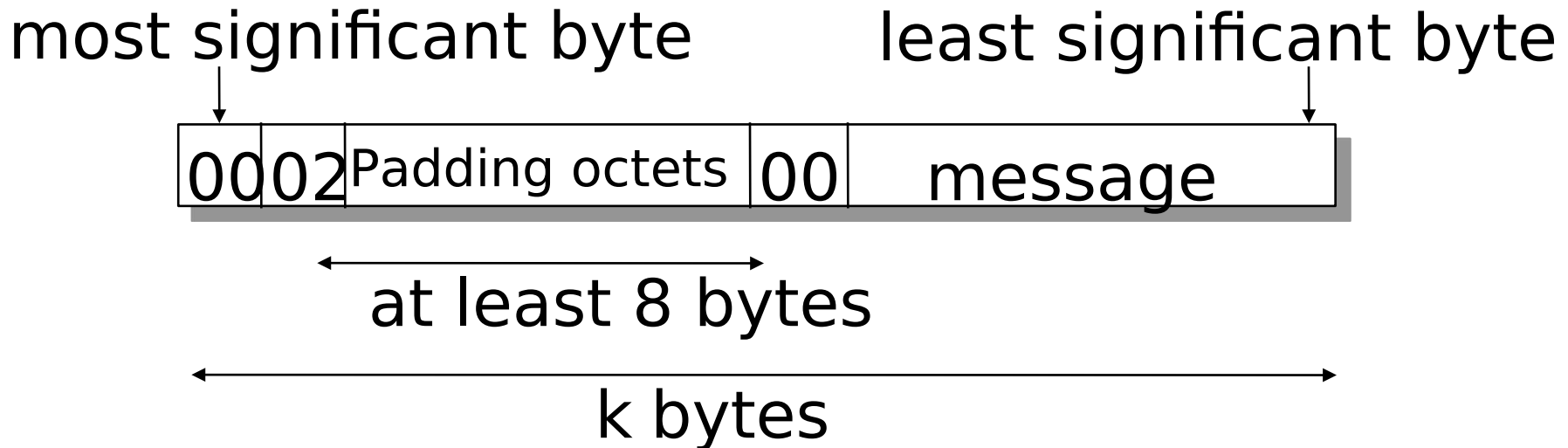
# CMS

- How to MAC, sign and/or encrypt application data in an ASN.1 oriented way
  - E.g. CMS defines: SignedData and EnvelopedData
  - XML, JSON and CBOR equivalents started from here
- Algorithms and options same as X.509
- Latest CMS specification: RFC 5652
- But first, to encrypt, we need a bit of glue between arithmetic (for RSA) and ASN.1 BIT STRINGS – often uses PKCS#1 v1.5 format...

# PKCS#1 v1.5 Padding (encryption) RFC 8017

RSA modulus:  $n=pq$  of length  $k$  bytes;  
i.e.  $256^{k-1} < n < 256^k$

Padding octets are random but non-zero



# CMS SignedData (1)

```
SignedData ::= SEQUENCE {  
    version CMSVersion,  
    digestAlgorithms DigestAlgorithmIdentifiers,  
    encapContentInfo EncapsulatedContentInfo,  
    certificates [0] IMPLICIT CertificateSet  
                                OPTIONAL,  
    crls [1] IMPLICIT CertificateRevocationLists  
                                OPTIONAL,  
    signerInfos SignerInfos }
```



# CMS SignedData (2)

```
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 }
```

```
SignedAttributes ::= SET SIZE (1..MAX) OF Attribute
```

```
UnsignedAttributes ::= SET SIZE (1..MAX) OF Attribute
```

```
Attribute ::= SEQUENCE {  
    attrType OBJECT IDENTIFIER,  
    attrValues SET OF AttributeValue }
```

```
AttributeValue ::= ANY
```

```
SignatureValue ::= OCTET STRING
```

# CMS Message Specification

- Latest specification is RFC 8551
- Tells you how to:
  - Start with a MIME email message
  - Treat that like plaintext the CMS way
  - Then take the resulting bytes and make them into a MIME message
- Note: LARGE messages exist
  - Have to handle BER as well as DER

# CMS Certificate Specification

- Latest specification is RFC 8550
- Tells you how to interface an s/mime mail user agent with a PKI
- Tells you how to interpret RFC 5280 for s/mime purposes
  - E.g. How to include email addresses in certificates

# Wanna Try S/MIME?

- It's been a few years since I had a working s/mime setup (I use PGP mostly), but for your benefit...
- Last year, I tried this “free” service  
<https://www.actalis.com/s-mime-certificates.aspx>
- Verification email was Italian-first:-)
- Then they sent me a pkcs#12 file!
- That means they know the private key!!
- I didn't install that in my mail user agent
- I got Italian language emails this year reminding me that a certificate was going to expire (I think:-)
- Doesn't look good for ad-hoc use:  
[https://kb.mozillazine.org/Thunderbird\\_-\\_FAQs:\\_Get\\_a\\_n\\_SMIME\\_certificate](https://kb.mozillazine.org/Thunderbird_-_FAQs:_Get_a_n_SMIME_certificate)

# Pretty Good Privacy (PGP)

- PGP can do all that S/MIME does
- PGPMime is RFC 3156
- PGP's basic formats in RFC 4880
  - Not ASN.1 based (home-grown TLVs)
  - Currently being updated (I help co-chair that)
    - <https://datatracker.ietf.org/doc/draft-ietf-openpgp-crypto-refresh/>
- Web-of-trust model != X.509 PKI
  - But you don't have to
- Most important use-case? Maybe package signing
- Now natively supported in Thunderbird

# PGP Key Management

- X.509-based PKIs are hierarchies
- PGP web of trust (WoT) based on user's signing one another's keys, with possibly many signatures per public key
- PGP Key IDs are (truncated) hashes
- PGP key servers exist
- Usability: sucks:-(
- Details: lots of HOWTOs on the web

# S/MIME and PGP Deployment

- Most MUAs support s/mime or PGP either built-in or as an option
  - There are also “plug-in” products
- And mostly then *can* work together
  - I’ve used both, PGP currently seems more usable (with Thunderbird)
- But e2e secure mail is not ubiquitous
  - Why?

# e2e email security barriers

- Designs pre-date web user agent which changes trust model (where's the private key kept? Needs new infrastructure)
- Needs all major mailbox providers (yahoo, hotmail, gmail) to deploy the same thing which also needs to be implemented by all major user agent developers (microsoft, mozilla, apple, google)
- Public key retrieval needs to be fixed (doable if the above done, but a killer if not done), likely with some new PKI (doable but who's gonna pay?)
- Mail headers need to be protected as users don't get that S/MIME and PGP only protect body and not e.g. Subject, From (new enveloping protocol needed, work-in-progress but kludgy)
- We need to unify S/MIME and PGP or pick one or we'll lose interop (it's ok if the other soldiers on for some niches)
- Users don't care much, so it has to be entirely transparent for them (needs significant UI work, co-ordinated across MUAs and significant web-UAs)



# e2e email current attempts

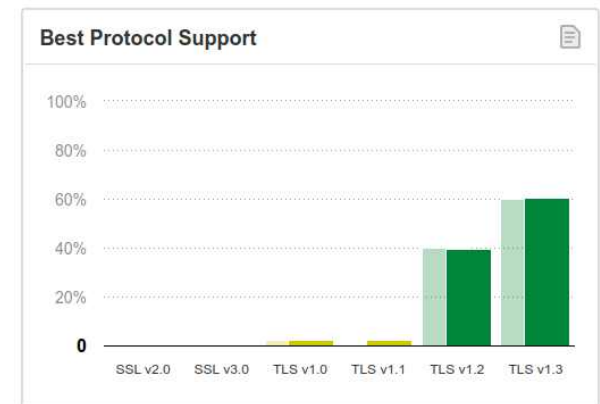
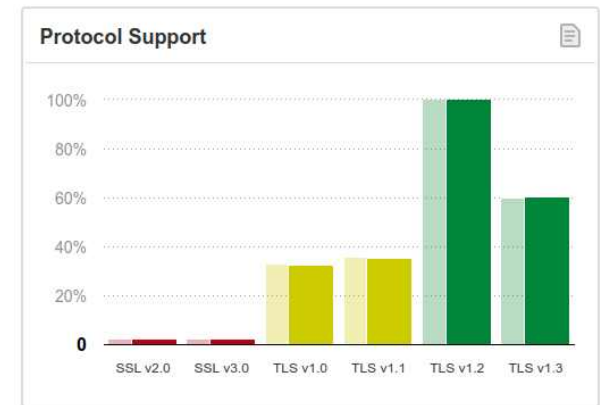
- (At least) two current projects have are trying to address general e2e mail security:
  - Autocrypt: <https://autocrypt.org/>
  - p≡p : <https://pep.foundation/>
- Some service providers try make e.g. PGP easier:
  - ProtonMail: <https://protonmail.com/>
- All worthy, none (yet) with real MUA/mail-mega-provider traction
- Most email security today depends on TLS for mail transport security which is hop-by-hop and not end-to-end
- e2e email security doesn't play so well with server-side anti-spam/malware/phishing techniques
- BUT, without e2e email security, it's all postcards!
  - And there are people reading those:  
<http://www.spiegel.de/international/europe/gchq-monitors-hotel-reservations-to-track-diplomats-a-933914.html>

# Transport Layer Security (TLS)

# Transport Layer Security (TLS)

Secure Sockets Layer (SSL) proposed by Netscape in 1994

- Works with any application that uses sockets to communicate e.g., ftp, http, nntp, telnet...
- Standardised as Transport Layer Security (TLS) in 1999
  - Name was compromise with Microsoft (their version was called PCT)
    - <https://tim.dierks.org/2014/05/security-standards-and-name-changes-in.html>
  - Latest: TLS1.3, RFC 8446
  - Most widely **deployed**: TLS1.2, RFC 5246 (just about?)
  - Oddly: RFC6101 is SSL3.0!



# SSL original services

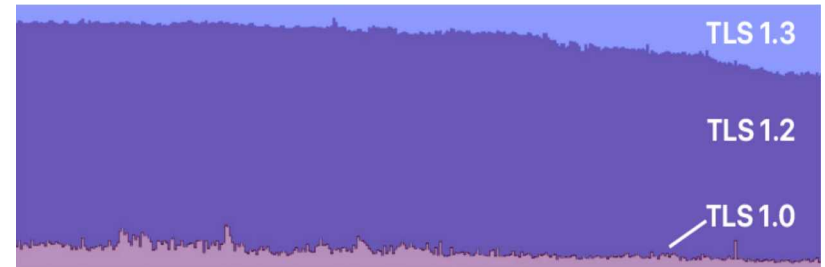
- Server Authentication - “buyer” can believe they are dealing with a bona fide “merchant”
  - (Optional) Client authentication
  - Digital certificates (X.509)
- Message Encryption - Buyer can send credit card details across the network without fear of interception
  - Also message integrity and replay-detection
- Relatively transparent to the user and application developer
  - Hence the name “secure sockets layer”

# Deployment of TLS

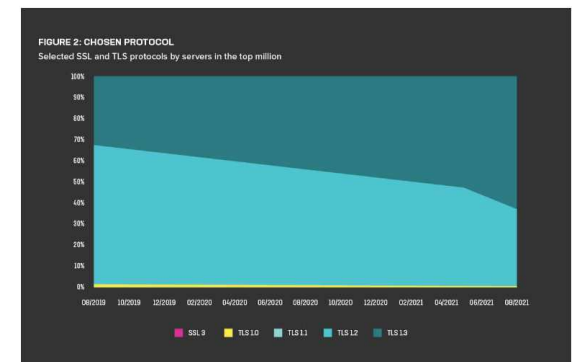
- Mid '90's: Used in Netscape Commerce Server
  - International “Step-up” encryption: Strong crypto for international banks, with special Verisign certificate
  - Built into Communicator 4.0 and later
- Now: everywhere, standard part of Web browsers, servers and all development platforms (PHP, python, golang etc.)
  - online trading, banking, commerce...
- “foo”/TLS/TCP on port 443 is now de-facto baseline for Internet-scale interop

# TLSv1.2 and TLSv1.3

- We'll look first at TLSv1.2, then lots more on TLSv1.3
- TLSv1.3 is a **major update** despite the minor version number change
- Older versions: next slide and RFC8996
- Deployment snapshots:
  - <https://ietf.org/blog/tls13-adoption/>  
~27-30% v1.3 Nov 2019
  - F5 2021 measurement: v1.3 chosen by 63% of top-1m servers in 2021
  - <https://www.ssllabs.com/ssl-pulse/>  
Best protocol v1.3 for ~60% Feb 2023



Cloudflare measurement from May 2018-May 2019



From: [draft-ietf-tls-oldversions-deprecate-12](#)

Best Current Practice

[Errata exist](#)

Internet Engineering Task Force (IETF)

K. Moriarty

Request for Comments: 8996

CIS

BCP: 195

S. Farrell

Obsoletes: [5469](#), [7507](#)

Trinity College Dublin

Updates: [3261](#), [3329](#), [3436](#), [3470](#), [3501](#), [3552](#),

March 2021

[3568](#), [3656](#), [3749](#), [3767](#), [3856](#), [3871](#),

3887, 3903, 3943, 3983, 4097, 4111,

4162, 4168, 4217, 4235, 4261, 4279,

4497, 4513, 4531, 4540, 4582, 4616,

4642, 4680, 4681, 4712, 4732, 4743,

4744, 4785, 4791, 4823, 4851, 4964,

4975, 4976, 4992, 5018, 5019, 5023,

5024, 5049, 5054, 5091, 5158, 5216,

5238, 5263, 5281, 5364, 5415, 5422,

5456, 5734, 5878, 5953, 6012, 6042,

6083, 6084, 6176, 6347, 6353, 6367,

6460, 6614, 6739, 6749, 6750, 7030,

7465, 7525, 7562, 7568, 8261, 8422

Category: Best Current Practice

ISSN: 2070-1721

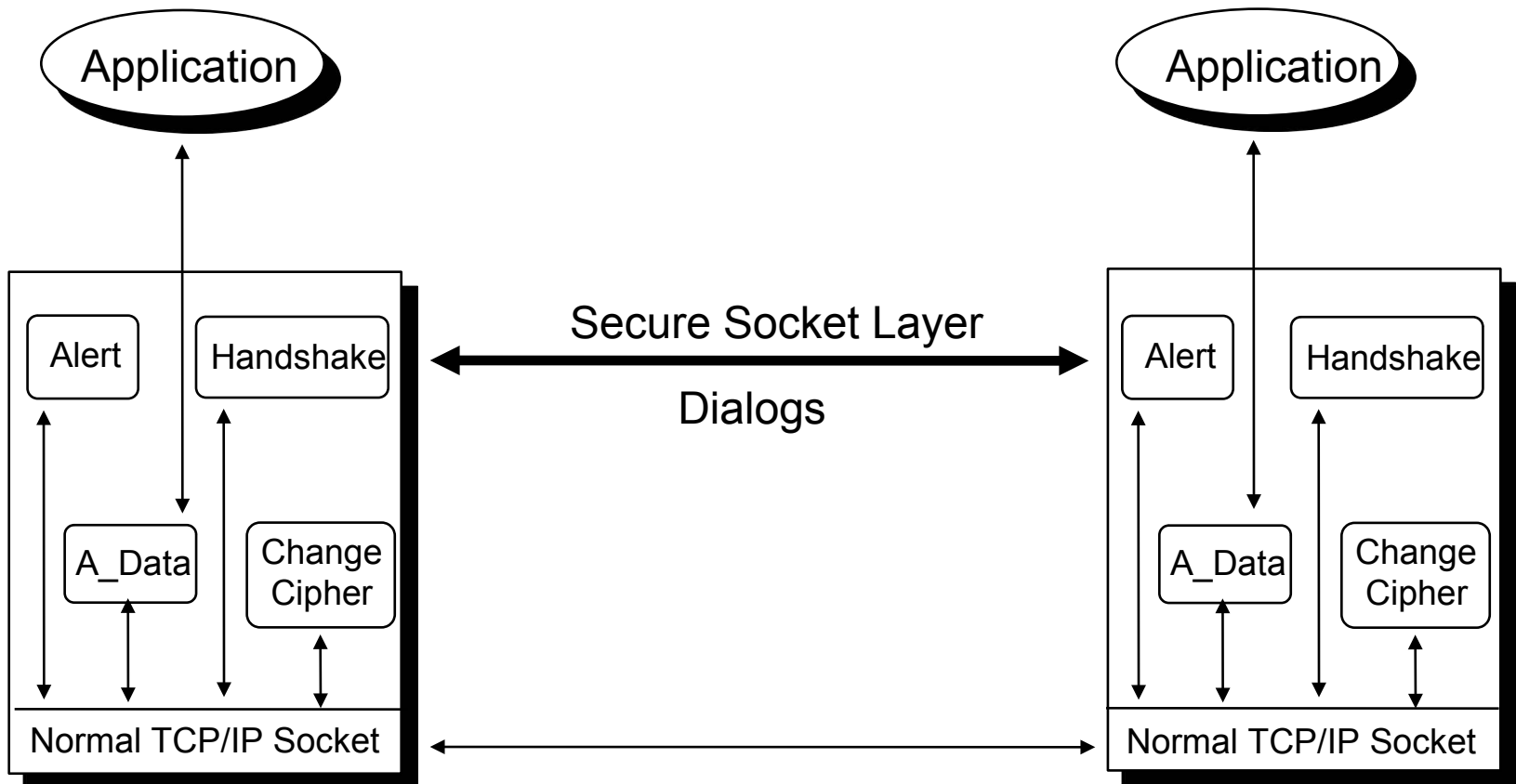
## Deprecating TLS 1.0 and TLS 1.1

### Abstract

This document formally deprecates Transport Layer Security (TLS) versions 1.0 ([RFC 2246](#)) and 1.1 ([RFC 4346](#)). Accordingly, those documents have been moved to Historic status. These versions lack

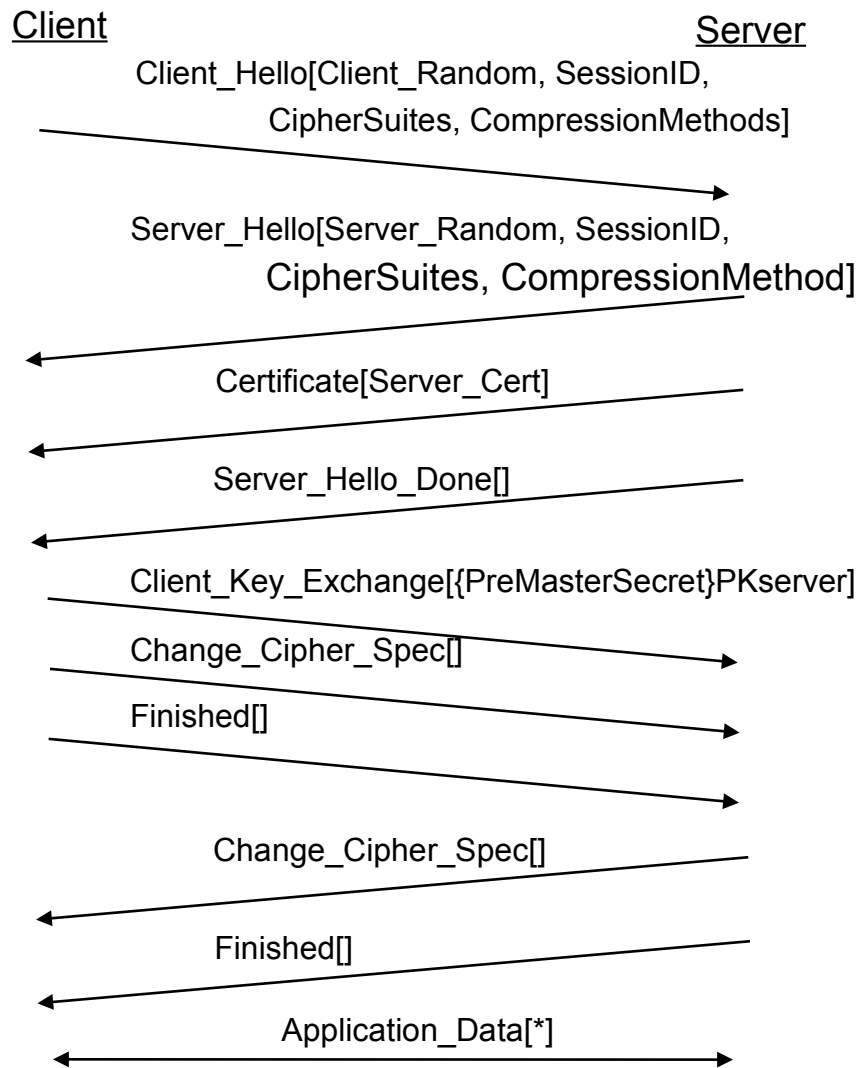
# Components of the TLS Protocol

- TLS broken into 4 interrelated sub-protocols



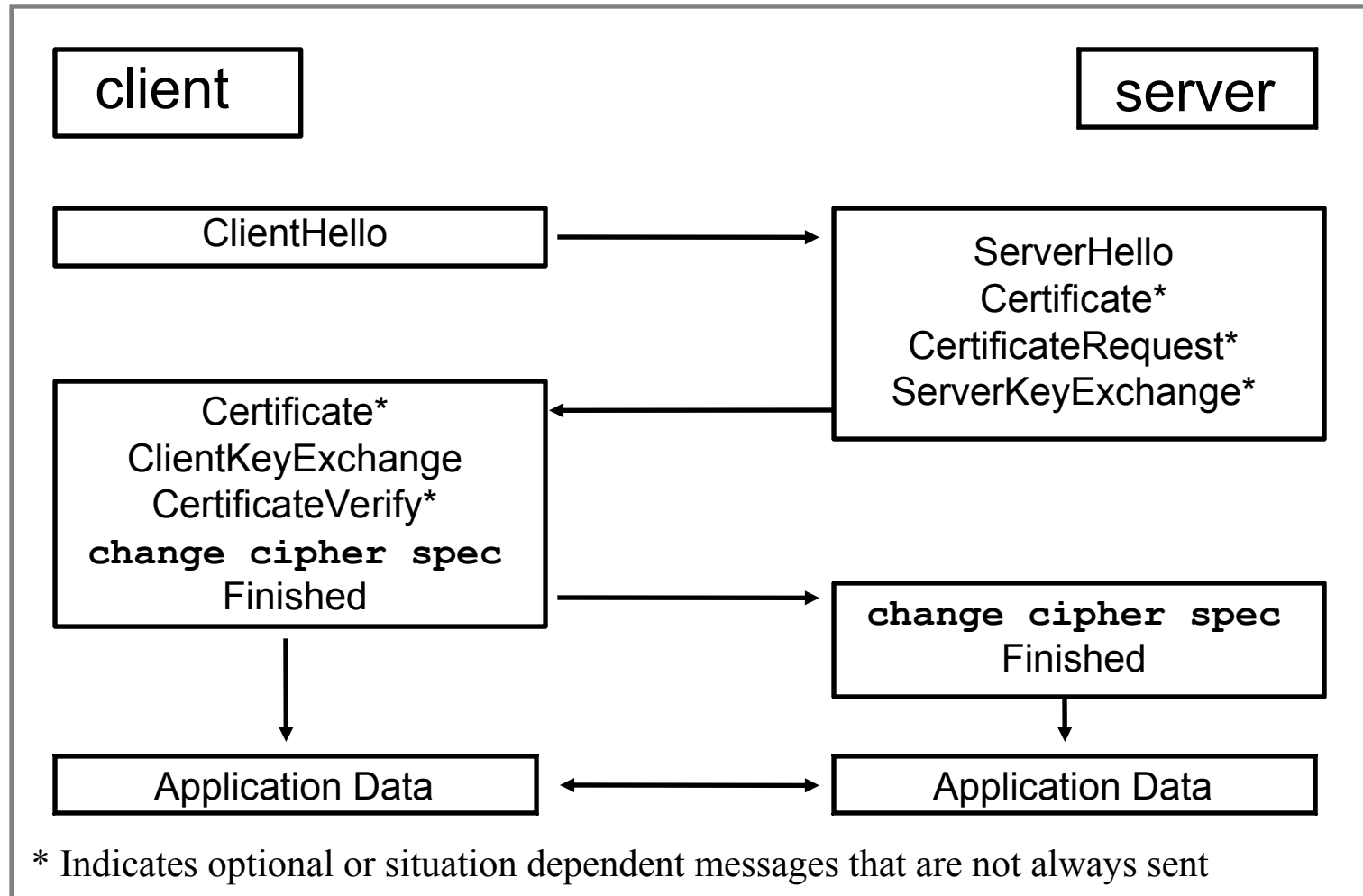


# TLSv1.2 Handshake Protocol



- Negotiate Compression Method and Cipher Suite
- Swap random quantities
- Client obtains server certificate path
- Client invents PreMasterSecret (48 bytes) and securely sends it to the server
- Keys Calculated by both
- Finished message using new algorithms
- Data send in A\_Data Units

# TLSv1.2 Handshake Protocol summary



# Computing Keys from the Pre-MasterSecret

- First compute MasterSecret
- $\text{MasterSecret} = f(\text{PreMasterSecret}, \text{Client.Random}, \text{Server.Random})$
- MasterSecret Used to prime key-generator
- $\text{KeyBlock} = f(\text{MasterSecret}, \text{Client.Random}, \text{Server.Random})$

$$\begin{aligned} \text{KeyBlock} = & \text{MD5}(\text{MasterSecret} + \text{SHA}('A' + \text{MasterSecret} + \text{ServerHello.Random} + \text{ClientHello.Random})) + \\ & \text{MD5}(\text{MasterSecret} + \text{SHA}('BB' + \text{MasterSecret} + \text{ServerHello.Random} + \text{ClientHello.Random})) + \\ & \text{MD5}(\text{MasterSecret} + \text{SHA}('CCC' + \text{MasterSecret} + \text{Server.Hello.Random} + \text{ClientHello.Random})) + \dots \end{aligned}$$

|          |                   |
|----------|-------------------|
| KeyBlock | Client_MAC_Secret |
|          | Server_MAC_Secret |
|          | Client_Key        |
|          | Server_Key        |
|          | Client_Stream_Key |
|          | Server_Stream_Key |

Partition key-stream  
into individual  
quantities

# Applying the Keys to Application Data (TLSv1.2 Record Layer)

**Divide stream into blocks**

Fragment of User Data  
 $\leq 2$  Bytes

**Compress**

Compressed Fragment

**Compute MAC**

Compressed Fragment

MAC

PAD

PAD  
Length

Block Cipher (with padding) or  
Stream Cipher

|                          |                     |                   |                   |
|--------------------------|---------------------|-------------------|-------------------|
| Application<br>Data Ind. | Protocol<br>Version | Payload<br>Length | Encrypted Payload |
|--------------------------|---------------------|-------------------|-------------------|

# TLSv1.2 Ciphersuites

- SSL/TLS supports various cryptographic options
  - Digest algorithms, key transport, ...
- Design decision was to represent all choices made in a single value
  - Ciphersuite – a 16 bit number
  - TLS\_RSA\_WITH\_3DES\_EDE\_CBC\_SHA
- Interesting consequences...

# A TLSv1.2 Handshake Visualisation

<https://tls.nqsb.io/>  
**BUMMER! Offline**

Showed the messages you exchange with that server and references bits of text from RFC 5246

Was Nice!

Ironically: nqsb == not quite so broken;-)

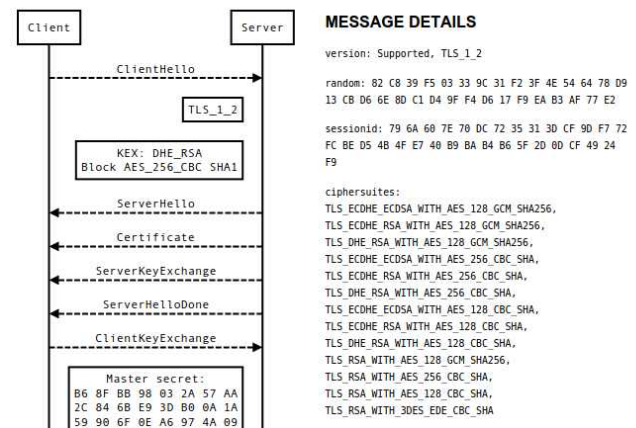
<https://tls13.xargs.org/> similar for TLSv1.3

## OCAML-TLS DEMO SERVER

When connecting to a secure site (<https://>), your browser automatically initiates a secure connection using [transport layer security \(TLS\)](#). The sequence diagram below shows you the [TLS handshake](#) that just took place when your browser connected to this web server. We traced it using our [OCaml-TLS](#) implementation.

The dotted lines represent unencrypted messages, while the solid lines indicate encrypted messages. Clicking on a message shows details about the exchanged data and the corresponding section of the [RFC 5246 \(TLS-1.2\)](#) specification. Subsequent messages of the same type are condensed (marked with "\*\*").

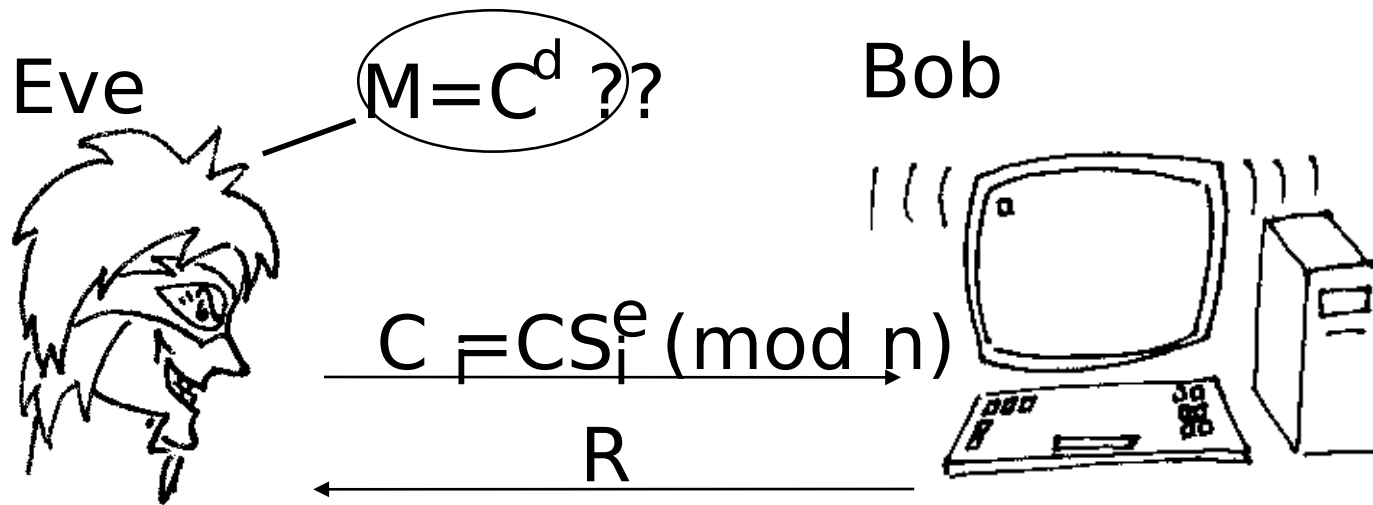
[Renegotiate!](#) lets our server send a *Hello Request* message to the client, and JavaScript fetches a new trace and updates the sequence diagram. Our demo server picked a protocol version and ciphersuite at random.



# Bleichenbacher

- “Materials” section has a full paper & ppt
  - If you **completely** understand the attack, you're doing very well!
- Basis
  - PKCS#1 v1.5 padding adds formatting to the data
  - If I have an “oracle” that'll attempt decryption and tell me when the recovered plaintext has the PKCS#1 v1.5 padding then I gain knowledge
- This happened with TLS!
  - “Million message” attack

# How the attack works: Overview



If a message  $C_1$  is PKCS conforming then

$$2^{256 \cdot (k-2)} - 1 < MS < 3 \cdot 2^{256 \cdot (k-2)}$$

- This is an adaptive chosen-ciphertext attack
- RFC3218 describes the attack and ways to avoid it.



# Other TLS-relevant Stuff

- ~~Key-pinning in HTTP (HPKP): RFC 7469~~
- HTTP Strict Transport Security (HSTS): RFC 6797
- OSCP Stapling (RFC 6066)
- MTA Strict Transport Security (RFC 8461)
- Datagram TLS (DTLS) for connectionless applications (e.g. RTP): RFC 9147 for DTLS1.3, RFC 6437 for DTLS1.2
- We'll look at TLSv1.3 (RFC8446) in detail in a bit and Encrypted Client Hello (for TLSv1.3 only)
  - <https://tools.ietf.org/html/draft-ietf-tls-esni>

# IP Security (IPsec)

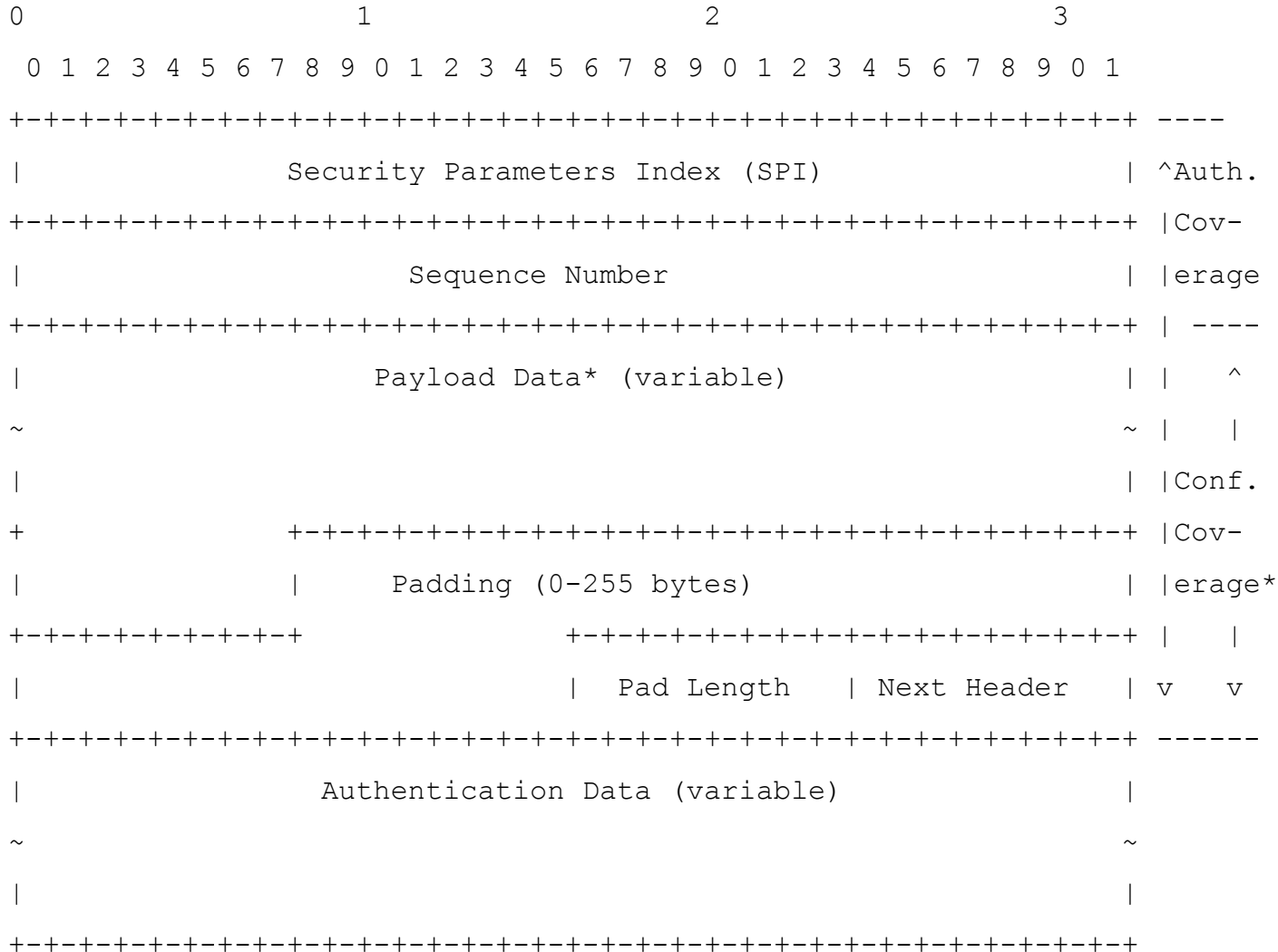
# Ipssec overview

- “Security Architecture” RFC 4301
  - Key exchange, data encryption and data integrity mechanisms at the IP layer
- Optional as part of an IPv4 stack
  - (Used to be) Mandatory to implement as part of IPv6 stacks
  - Note: Mandatory to implement (MTI) != “MUST use”
- Tunnel/Transport modes
  - VPNs using tunnel mode common
- Security policy DB
  - How to handle (un)protected packets

# IP Security (IPsec)

- Took soooooo loooooong and produced such a complex outcome that they have a 2011 document roadmap (RFC 6071).
- Start with RFC 4301, the architecture
- Main moving parts: AH (RFC 4302), ESP (RFC 4303), and IKEv2 (RFC 7296)
  - AH mostly deprecated
  - IKE -> IKEv2 due to IKE/ISAKMP/... complexity, do NOT bother with IKEv1
- So, we'll only look at ESP & IKEv2

# ESP – Encapsulated Security Payload



# ESP terms

- Specification: RFC 4303
- Security Parameters Index (SPI) selects amongst different
  - Algorithms; Keys; etc.
  - SPI (+ dest. IP) = Security Association (SA)
- Seq# for anti-replay
  - Never cycles (new SA needed)
- Next header specifies payload protocol
- SA's are directional
  - So we use different keys between Alice and Bob as compared to between Bob and Alice

# ESP – some features

- ESP allows some basic level of traffic hiding
  - Padding (up to 255 bytes) to disguise data length
  - Tunnel mode between gateways
- Data expansion
  - About +19 bytes per packet, possibly worse
  - Can be serious (telnet)

# IKE - Internet Key Exchange

- IKEv1 (RFC 2409) is a mess of:
  - ISAKMP (rfc2408)
  - OAKLEY (rfc2412) and SKEME (not an rfc)
  - DOI (rfc2407)
- IKEv2 (RFC 7296) is a single document that's much better
  - But is 142 pages long;-(
- Wasn't that simple!



# IKEv2 (1)

- Provides protocol to...

- Mutually authenticate

- Exchange keys

- Based on:

- D-H and

- Pre-shared secrets or RSA

# IKEv2 (2)

- Establishes an IKE-SA and one (or more) CHILD-SA
- Generally requires 4 or 6 messages
  - IKE\_SA\_INIT (req/rep)
  - IKE\_AUTH (req/rep)
  - CREATE\_CHILD\_SA (req/rep)

# IKEv2 Phase1

## IKE\_SA\_INIT & IKE\_AUTH

Initiator

Responder

-----

-----

HDR, SAi1, KEi, Ni -->

<-- HDR, SAr1, KEr, Nr, [CERTREQ]

HDR, SK {IDi, [CERT,] [CERTREQ,] [IDr,]  
AUTH, SAi2, TSi, TSr} -->

<-- HDR, SK {IDr, [CERT,] AUTH,  
SAr2, TSi, TSr}

# IKEv2 Phase2

## CREATE\_CHILD\_SA

Initiator

Responder

-----

-----

HDR, SK {SA, Ni, [Kei], [TSi, Tsr]} -->

<-- HDR, SK {SA, Nr, [Ker], [Tsi, TSr]}

# Some IKEv2 Features

- Not IKEv1!
- Uses ESP to protect things
- Misc:
  - PFS, NAT-capable, Traffic Selectors, Liveness checks, Cookies
- Still a bit clunky though!
  - E.g. Compression (rfc2393), ESP and then AH nested SAs

# IPsec summary

- Tunnel mode widely used for VPNs and works just fine
  - Transport mode hardly used at all
- IKE interop today isn't perfect (with certs), but is ok
  - Some vendor-specific stuff, e.g. For RADIUS/legacy auth
- Deployment issues:
  - Windows, NAT, Firewall, ECN, Opportunistic Keying, APIs
  - IKEv2 work aims to address a bunch (but not all!) of these

# Another IPsec overview

- Good March 2022 presentation on IPsec by an expert (Paul Wouters)
  - <https://datatracker.ietf.org/meeting/113/materials/slides-113-saag-introduction-to-ipsec-00>
- If his content contradicts mine, believe him:-)

Other protocols:  
kerberos, SSH, wireguard



# Kerberos

- Originally developed as part of MIT project athena
  - RFC4120 (but RFC1510 may be easier)
- Designed for many users working with few(-ish) servers
  - Largely symmetric key (shared secret) based
- Based around clients interacting with a Key Distribution Centre (KDC) aka:
  - Authentication server (AS)
  - Ticket Granting Server (TGS)

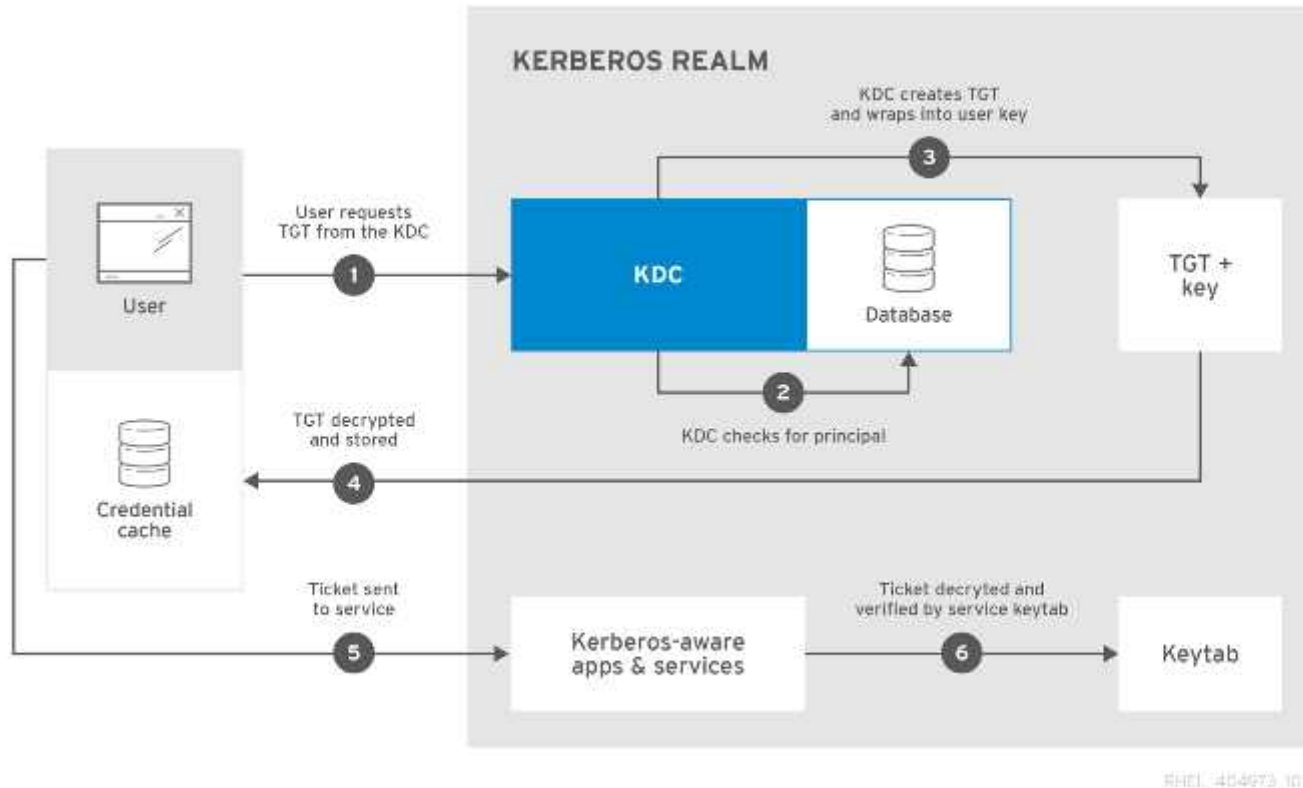
# Kerberos

- Uses ASN.1 again! (sort-of)
- Latest spec: RFC 4120
- Typical use:
  - Client sends AS\_REQ to KDC gets AS\_REP containing TGT
  - Client sends TGS\_REQ to KDC (includes TGT) and gets TGS\_REP (including Ticket)
  - Client sends KRB\_SAFE to server including Ticket

# A Ticket

```
Ticket ::= [APPLICATION 1] SEQUENCE {  
  tkt-vno [0] INTEGER (5),  
  realm [1] Realm,  
  sname [2] PrincipalName,  
  enc-part [3] EncryptedData -- EncTicketPart }  
-- Encrypted part of ticket  
  
EncTicketPart ::= [APPLICATION 3] SEQUENCE {  
  flags [0] TicketFlags,  
  key [1] EncryptionKey,  
  crealm [2] Realm,  
  cname [3] PrincipalName,  
  transited [4] TransitedEncoding,  
  authtime [5] KerberosTime,  
  starttime [6] KerberosTime OPTIONAL,  
  endtime [7] KerberosTime,  
  renew-till [8] KerberosTime OPTIONAL,  
  caddr [9] HostAddresses OPTIONAL,  
  authorization-data [10]  
    AuthorizationData OPTIONAL }
```

# Kerberos Flows



**Figure 11.1. Kerberos Authentication**

[https://access.redhat.com/documentation/en-us/red\\_hat\\_enterprise\\_linux/7/html/system-level\\_authentication\\_guide/using\\_kerberos](https://access.redhat.com/documentation/en-us/red_hat_enterprise_linux/7/html/system-level_authentication_guide/using_kerberos)

# Kerberos Things to Note

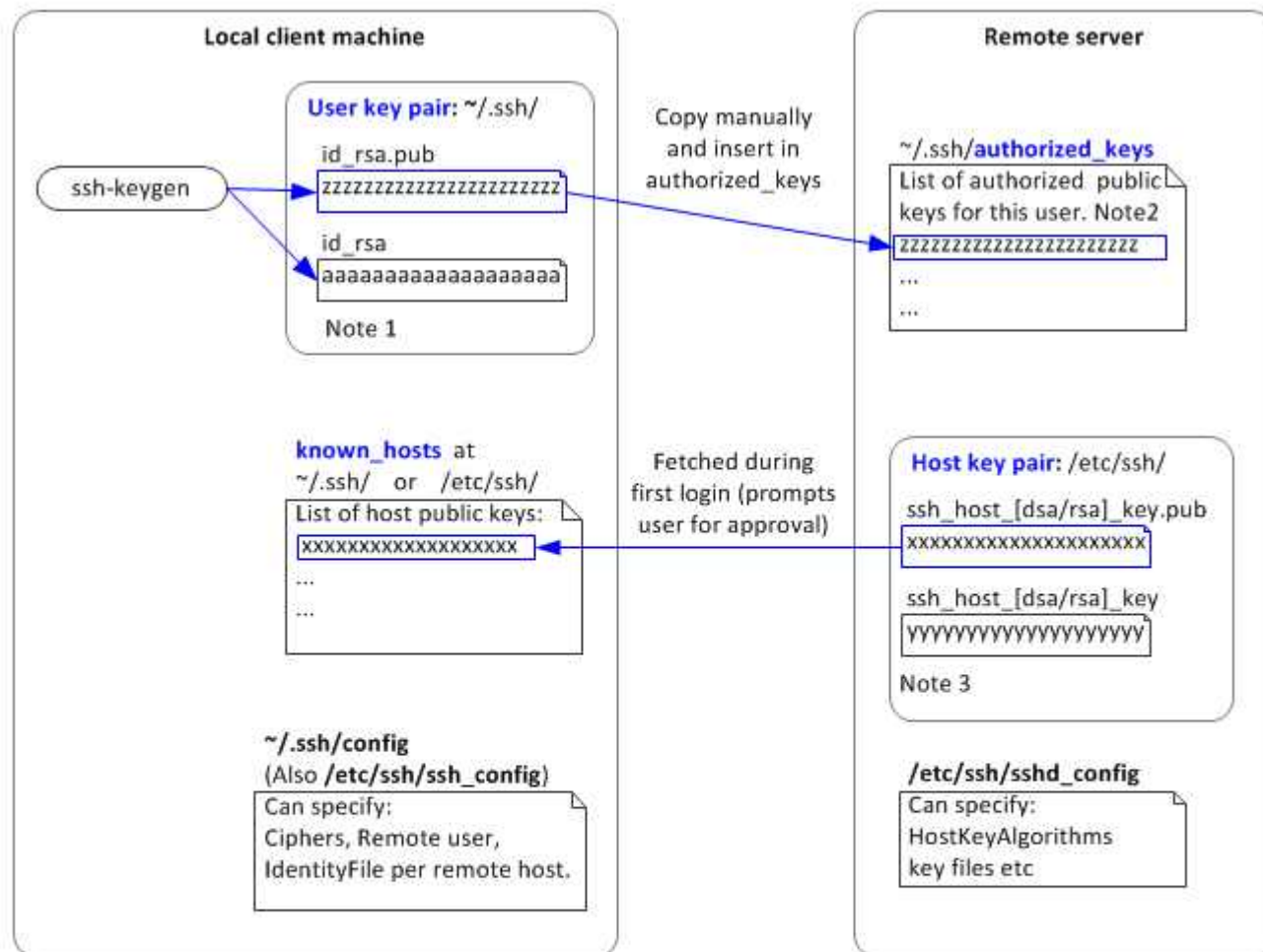
- Loose clock sync. Required
- Kerberos realm is like but not the same as a DNS domain
- Inter-realm and public key based operation defined but not used that often
- Used in Windows security: KDC is part of ActiveDirectory server
- Various authorization data extension have been done over the years
- AS\_REQ can contain dictionary attackable password or something better (usually the latter in modern implementations)

# Secure Shell (SSH)

- Architecture: RFC 4251
- Details in RFCs 4252 (transport protocol), 4253 (user auth), 4254 (multiplexing)
- Entirely typical flows – do D-H, authenticate in encrypted tunnel, application data in channel in encrypted tunnel
- Tends to be more driven by widely-used implementations rather than the RFCs, so generally implementations are ahead of the RFCs, sometimes significantly so esp. for extensions and algorithms, e.g.: <https://www.openssh.com/specs.html>
- Next 2 slides from:  
<https://serverfault.com/questions/935666/ssh-authentication-sequence-and-key-files-explain>

## Files involved in SSH connection: preparation

gwideman 2018-10-14

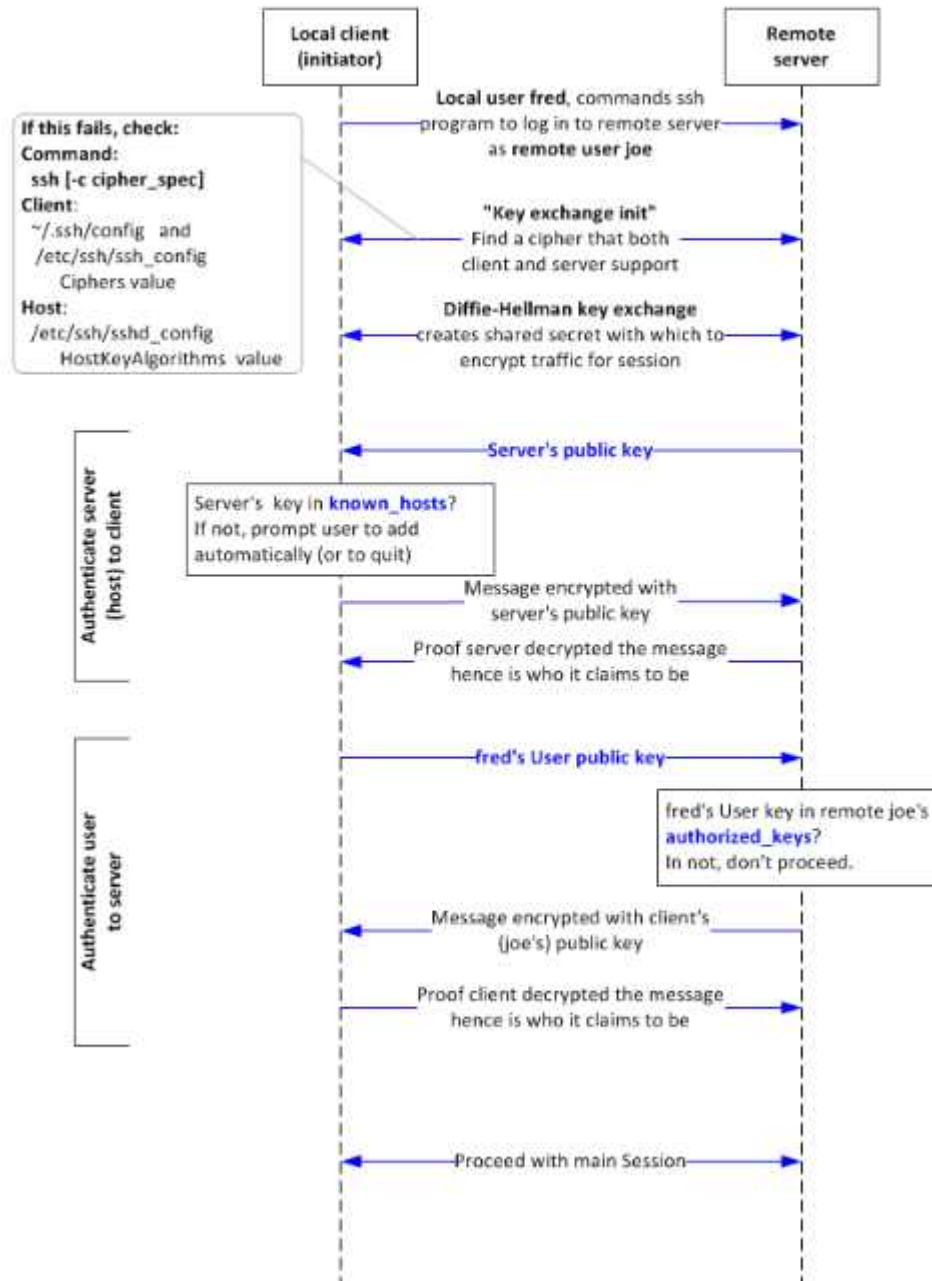


### Notes:

1. A user can, and often will, have more than one user key pair, in files with distinctive names. Commands that use key files allow specifying which files to use.
2. User account on the remote host need not have the same username as that on the local initiating machine. I.e: In local ssh or rsync command, specify the remote user account by which to log in.
3. Host key pair is created at previous installation time, such as when installing openssh.

## Files involved in SSH connection: In use

gwideman 2018-10-14





# SSH Messages

Old style message descriptions, e.g. RFC 4252 describes the value of 'signature' as a signature by the corresponding private key over the following data, in the following order:

|         |  |
|---------|--|
| string  | session identifier                       |
| byte    | SSH_MSG_USERAUTH_REQUEST                 |
| string  | user name                                |
| string  | service name                             |
| string  | "publickey"                              |
| boolean | TRUE                                     |
| string  | public key algorithm name                |
| string  | public key to be used for authentication |

# SSH things to note

- SSH is the epitome of the Trust On First Use (TOFU) model in how it handles known host keys on the client
- Be careful of VMs – easy to clone host key accidentally, e.g. if using puppet or similar
- In almost all cases: turn off password authentication and only allow public key based auth for systems you manage
- Be careful of user key pairs – it's very easy to end up with lots of old keys (e.g. for ex-employees!) in `authorized_keys` files
- SSH tunnelling is a fine thing – use a jump-off host to which you have a login to connect to others inside the LAN of the jump-off host – but as usual be careful in allowing this if you're a sysadmin

# Wireguard-1

- Newish (2016), non-standard, work-in-progress VPN tunnelling protocol, but now (Jan 2020) accepted into upstream Linux kernel
- Protocol description: <https://www.wireguard.com/papers/wireguard.pdf> and/or <https://www.wireguard.com/protocol/>
- Design goals: simpler, quicker than IPsec or OpenVPN using only modern crypto, ~4K LOC in kernel
- `wg` tool acts like `iwconfig` for managing interfaces, e.g. `wg0`, use normal OS tools (e.g. `ip`) to create i/f and handle addresses and routes
- Local interfaces are associated with a static curve25519 key pair, remote peers with a public key, ephemeral curve25519 keys are generated in 1RTT handshake
- Has a cookie mechanism for DoS mitigation, triggered if responder is “under load”
- Optional PSK can be bound with key exchange for post-quantum future-proofing
- Traffic is protected using Chacha20poly1305 and encapsulated in UDP

# Wireguard-2

- Public key distribution is out of scope – requires some other tooling, same as SSH
- Wireguard doesn't allocate IP addresses for clients – that's also considered out of scope and needs other tooling (apparently, haven't tried) – claimed to be problematic for some VPN operators who don't want to configure/log anything per-client
  - <https://git.zx2c4.com/wg-dynamic> was being developed in 2019, not sure of status
- Various timers and optional keepalives built-in (for NAT)
- If you want firewalling – just use a firewall (e.g. `ufw`) as if the traffic were in clear (no IPsec policy DB here:-)
- Protocol (designer) is v. opinionated – deliberately no crypto agility at all within protocol versions (that's also “modern”:-)
- Performance and attack surface look good, will be interesting to see how this evolves

# Mix'n'match

- PKI vs. Shared-secret vs. Trusted public keys
- TLS vs IPsec vs S/MIME vs CMS vs PGP vs Kerberos vs SSH vs Wireguard
- When should you pick which?

# Recent hour(s)...

- PKI model and protocols
  - SMIME formats and secure email
  - **TLS protocol (TLS1.2 or TLS1.3)**
  - IPsec
  - Kerberos
  - SSH
  - Wireguard
- Knowing **one** of these in detail is enough for exam purposes – you **will** need to read the source materials