

Standard Security Protocols

*Going up the stack:
TLS, IPsec, Kerberos and all that*

Next hour...

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

Why?

- 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
- Open-source projects
 - e.g.: Apache, WHATWG
- Open-source commercial alliances
 - e.g.: OpenStack
- Operational entities:
 - e.g. ICANN, RIPE, ARIN,...
- Topic specific alliances
 - e.g. M3AAWG

Types of standards

All SDOs have difference categories of standard

- _ RFC1149; <http://www.blug.linux.no/rfc1149>
- _ Draft versions may be published or not,
long-lived or not, rubbish or not

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

But note: All SDOs have some business
model, even the best 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)
 - Recent good news there wrt “lightweight” crypto/NSA:
https://www.schneier.com/blog/archives/2017/09/iso_rejects_nsa.html
 - Even more X.509 (PKI stuff ITU-T)
 - Various ITU telephony specs
 - Some inheriting from/profiling IETF

Internet Engineering Task Force (IETF)

- No members: 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:-)

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:
 - WebCrypto, WebAppSec, WebRTC
 - Focus more on browser APIs and not protocols

IEEE Standards Association

- Individual memberships but meeting attendance counts

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

- Security:
 - IEEE 802 – various security things, WPA etc.
 - Privacy study group looking at MAC address randomisation

OASIS

- Membership organisation (\$5-10k per annum)

<https://www.oasis-open.org/>

- Vendor driven
- “Cyber threat intelligence” (CTI)
- Lots of oldish security groups:
 - SAML, XrML, XACML, WSS, DSS

Others

- Trusted Computing Group

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

- Bluetooth

<https://www.bluetooth.com/>

- 3GPP <http://www.3gpp.org/>

- GSMA <http://www.gsma.org/>

- ANSI <https://www.ansi.org>

- ETSI <https://www.etsi.org>

- WHATWG <https://whatwg.org/>

- Open Mobile Alliance
<http://www.oma.org>

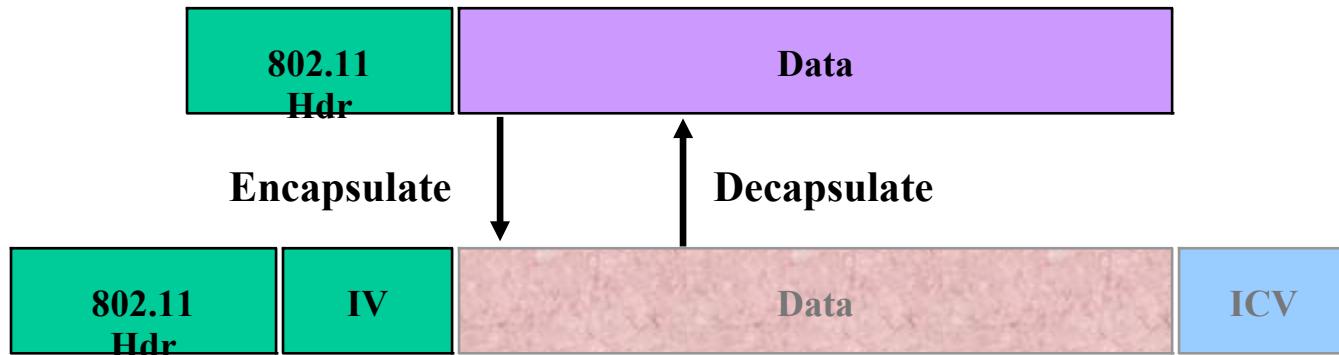
“Good” examples

- 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: IKE
- IEEE: WEP (or is it?)

WEP Encapsulation

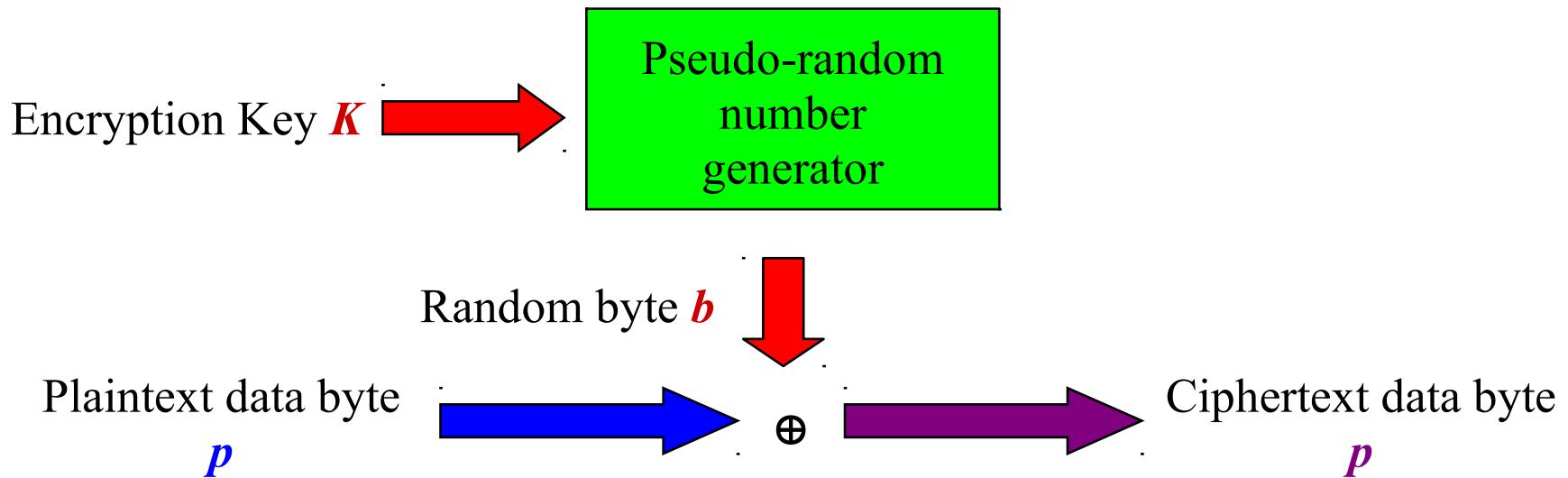


WEP Encapsulation Summary:

- 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 ?

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

$$c'_2 = p'_2 \oplus b$$

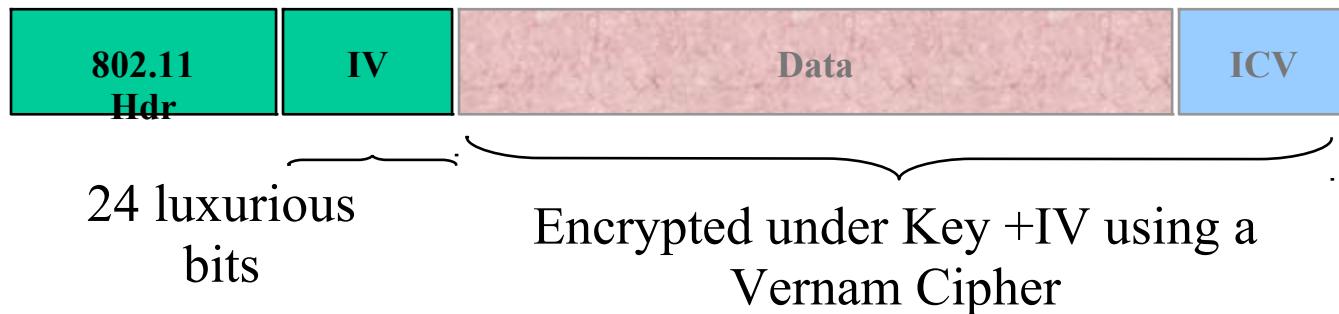
Then:

$$c'_1 \oplus c'_2 = (p'_1 \oplus b) \oplus (p'_2 \oplus b) = p'_1 \oplus p'_2$$

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 $P_n = P_{n-1} + (n-1)(1-P_{n-1})/2^{24}$ 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)

- Ways to 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.

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 changes like RED, AES alg.

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 nuts 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

Questions

- Question: How many cryptographic algorithms should we standardise and when?
- Question: WEP was broken when deployed, and then fixed. Same is true of SSL/TLS. Was that better or worse than IPsec/IKE which took 10 years to develop?

Standard Security Structures and Protocols

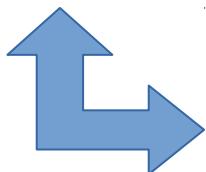
PKI, S/MIME, SSL, Kerberos, IPsec and all that jazz

Materials

- Lots of RFCs
- <https://datatracker.ietf.org/wg/>
- Bleichenbacher/"Avoiding the million-message"

Next hour(s)...

- PKI model and protocols
- SMIME formats and secure email
- SSL/TLS protocol
- IPsec
- Kerberos



Knowing one of these in detail is enough for exam purposes

Public Key Infrastructure (PKI)

- 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. Name) 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 public key concept involved publishing public keys in a newspaper
- Computing equivalent suggested in early 1980's
- First standard was X.509 in 1988
- IETF X.509 profile is in **RFC 5280**
- Used by TLS, S/MIME and lots of other protocols

X.509-based PKI Problems

- Everyone sensible hates this stuff
 - It's really old, gnarly & horrible
- Every now and then someone suggests replacing it with <foo>
 - So far, no <foo> has been sufficiently better to displace X.509 based PKI (sadly)
- Maybe in 5-10 years it'll be less important, but for now we have to suffer with it.

Certificates (1)

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

- Who knows what ASN.1 is?
 - An abstract syntax notation
 - With tag, length value encoding schemes (BER, DER, PER)
 - SEQUENCE -> 0x30, INTEGER -> 0x02
 - PITA

Certificates (2)

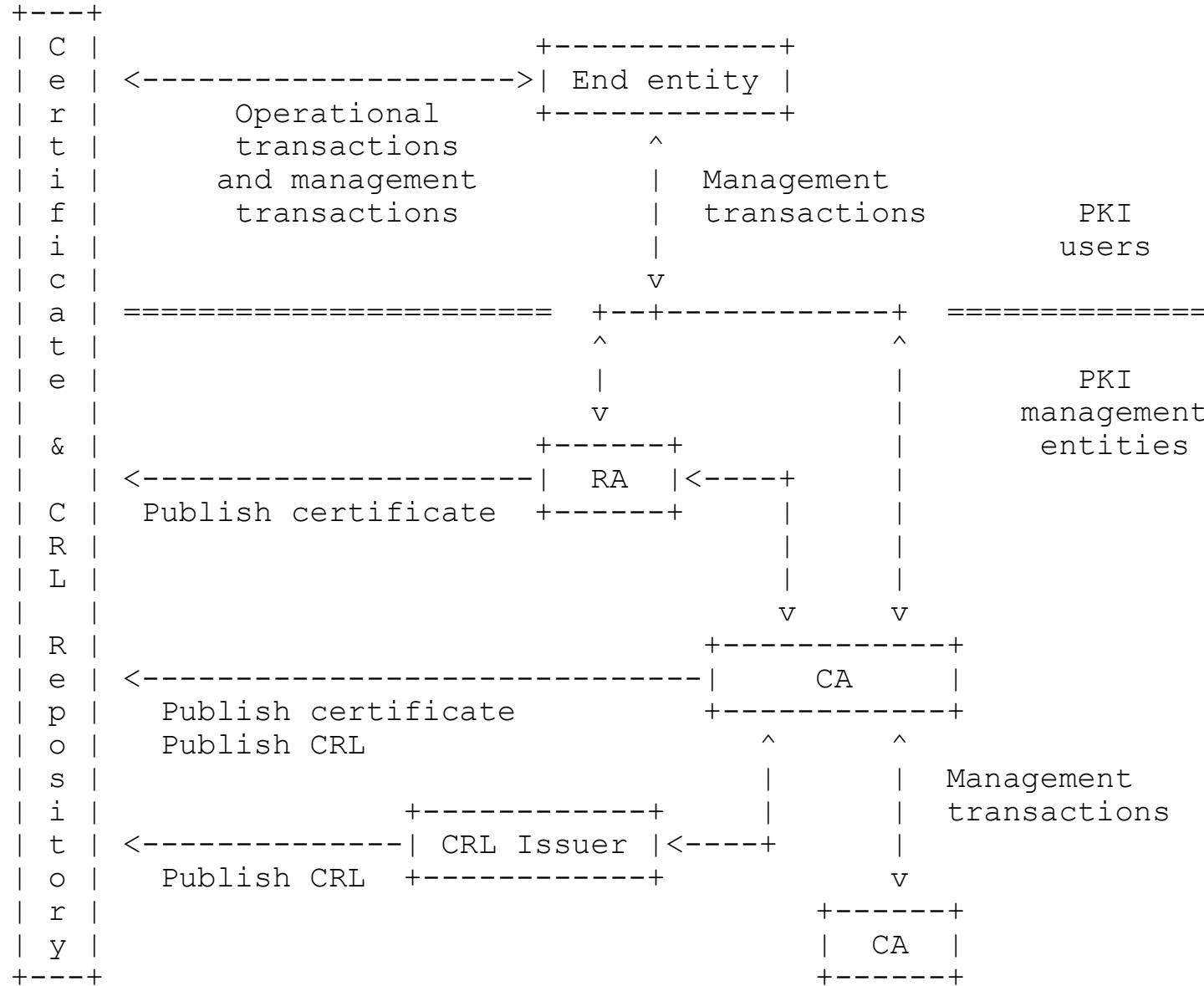
Certificate Revocation Lists

- A black-list of "bad" certificate serial numbers (plus list- and entry-extensions)
- Periodically issued by a CA
- Revocation = putting on black-list
- Also via on-line certificate status protocol (OCSP)
- Reasons to revoke: Key compromise, Key loss, Change of function, Uninstall web server...

To check a certificate

- Start with a (set of) trusted CAs
- Progress down certification path:
 - Is next-signature ok with previous public?
 - Is certificate revoked?
 - Continue
- Missing lots (see rfc5280)
 - E.g. Policy mappings (yuk!)

PKI Entities



PKI Protocols

- You need some to operate a PKI
- Registration: PKCS#10, proprietary, CMP, CMC, EST and now **ACME**
- Certificate retrieval: LDAP, DAP, HTTP, FTP, DPD
- Certificate validation: OCSP, DPV, CRL processing
- XKMS was a W3C attempt to do similar things
 - Deployment didn't happen

Roots/Trust Points

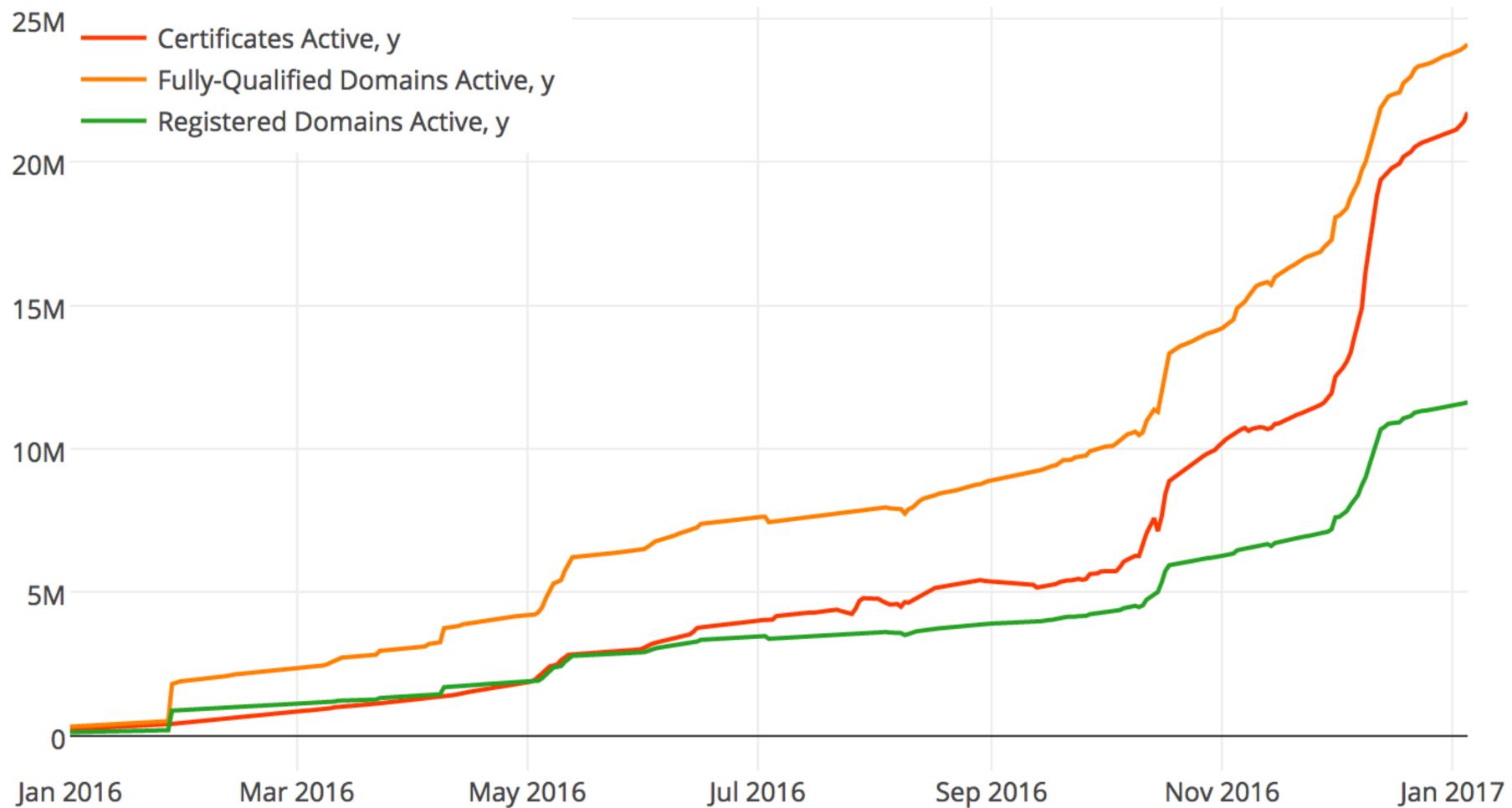
- Applications using PKI need to have a set of root CA public keys they “trust”
- Browsers have those – each with O(100) CAs in the list
- In/ex-clusion is highly political
 - <https://cabforum.org/> is a venue for some of that politics
- Other applications and OSes handle this similarly

Some good news though...

- <https://letsencrypt.org/> operating a free CA
 - Public beta since Dec 2015
- ACME protocol for automated certificate management
 - JSON based
 - <https://tools.ietf.org/wg/acme/>
- We'll see if it works this time;-)

Some good news though...

<https://letsencrypt.org/stats/>



Certificate Transparency (CT)

- There have been cases where CA's have been hacked or misbehave (later)
- CT is an attempt to improve the WebPKI (underlying https)
 - RFC6962 →
<https://tools.ietf.org/wg/trans/>
- Idea: append-only public logs of all certificates issued to allow detection of mis-issuance
 - <https://crt.sh/>

Attribute certificates

- Kind of a PKI-wart
- Certificate-like thing which has attributes instead of a subjectPublicKey
- Treat as experimental if you ever hear about them
- Can be used for role-based access control etc.

PKI Summary

- Mix of mature and new technology
 - Plenty of products/services and significant deployment experience
- Deployment and application integration problems exist
 - Can be overcome but expensive
- Still technology-of-choice for scalable key management
- Improvement is possible: e.g. ACME/CT

S/MIME

- There's a history here too!
 - PGP, PEM and MOSS
 - RSADSI's PKCS#7 based proposal
 - DKIM is a yet another development in this space
- Cryptographic Message Syntax (CMS) is the basis for S/MIME and other secure applications
- So S/MIME = CMS + Message-Specification + Certificate-specification

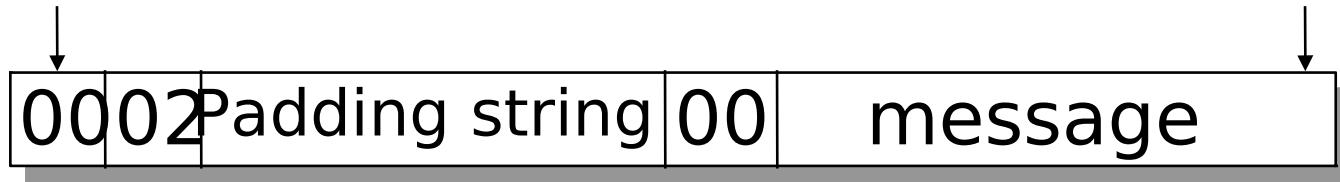
CMS

- How to MAC, sign and/or encrypt data in an ASN.1 oriented way
 - E.g. CMS defines:
 - SignedData
 - EnvelopedData
 - XML and JSON equivalents started from here
- Algorithms and options like in PKI
- Latest CMS specification: RFC 5652

PKCS#1 v1.5 Padding

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

most significant byte least significant byte



at least 8 bytes

k bytes

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 OFAttributeValue }
```

```
AttributeValue ::= ANY
```

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

CMS Message Specification

- Latest specification is RFC 5751
- Tells you how to:
 - Start with a MIME message
 - Treat that as 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 rfc5750
- Tells you how to interface an s/mime mail user agent with a PKI
- Tells you how to interpret PKIX RFCs for secure mail purposes
 - E.g. How to include email addresses in certificates
- Model to be followed

CMS Deployment

- Most MUAs support s/mime either built-in or as an option
 - _ There are also “plug-in” products
- And mostly then *can* work together
- But 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 email service 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, can be done 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)

Transport Layer Security (TLS)

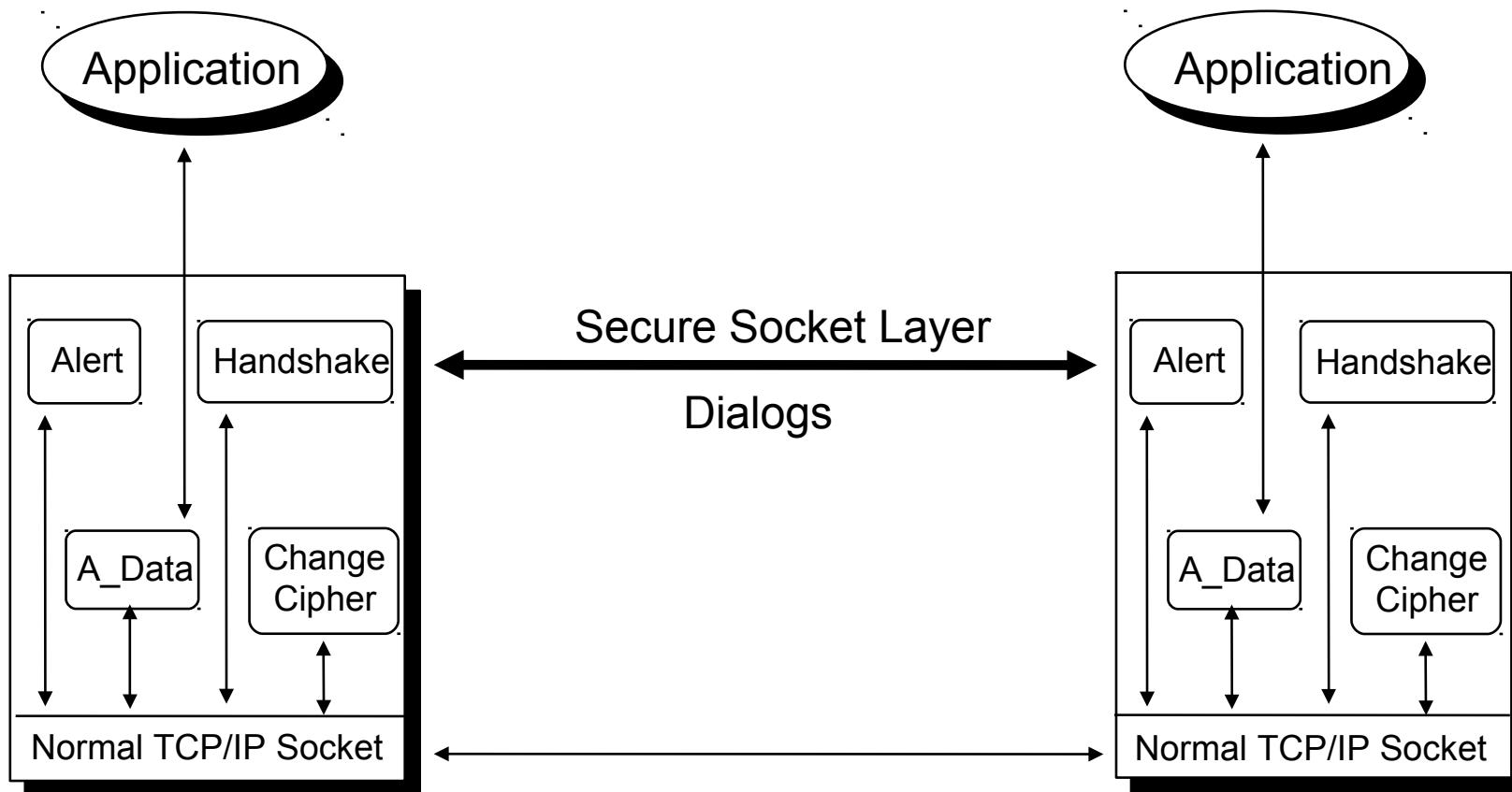
- Secure Sockets Layer (SSL): General Purpose Network Security Protocol proposed by Netscape in 1994.
- Designed to work with any application that uses sockets to communicate e.g., ftp, http, nntp, telnet...
 - Platform independent, application independent negotiations
- SSL standardised as Transport Layer Security (TLS)
 - Latest is TLS1.2: RFC 5246
 - Oddly: RFC6101 is SSL3.0!

TLS - services provided

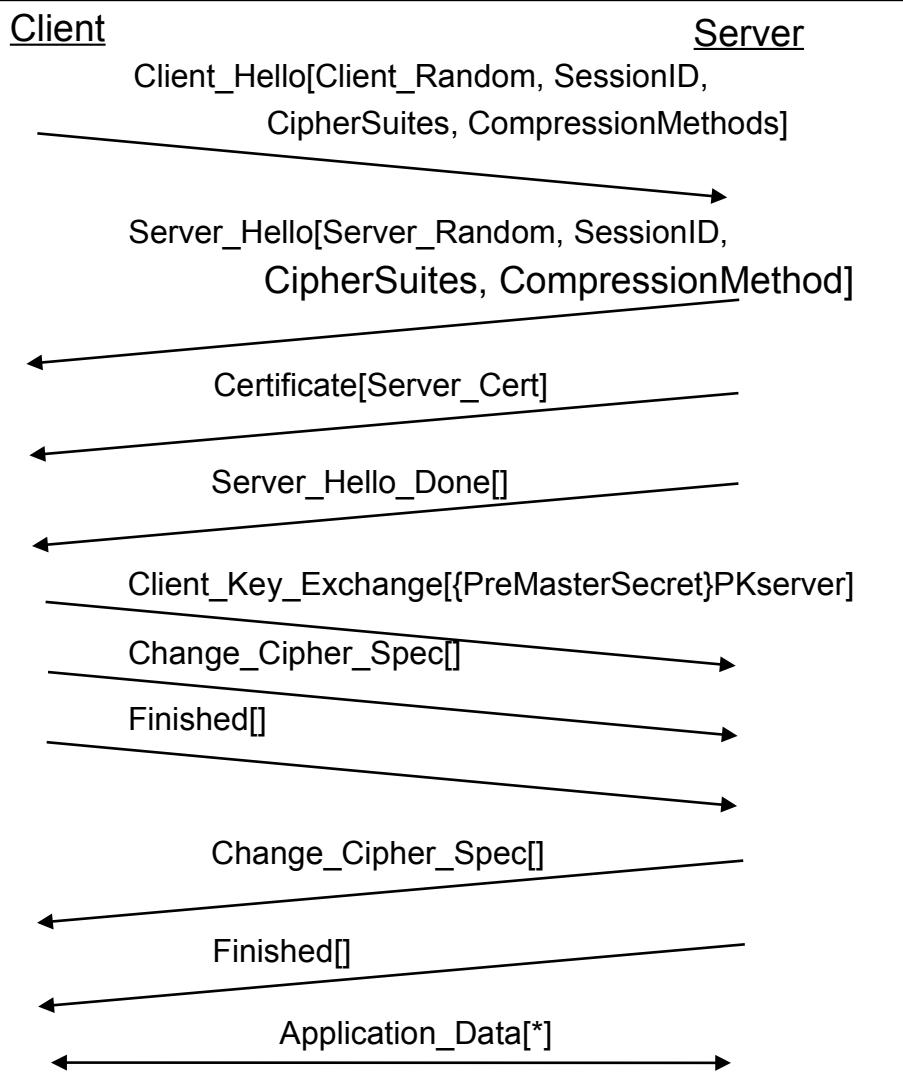
- Server Authentication - Buyer can believe they are dealing with a bona fide merchant
 - (Optional) Client authentication
 - Digital certificates (X.509)
- Message Encryption - Buyer can send credit card details across the network without fear of interception
 - Also message integrity and freshness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

Components of the TLS Protocol

- TLS broken into 4 interrelated sub-protocols

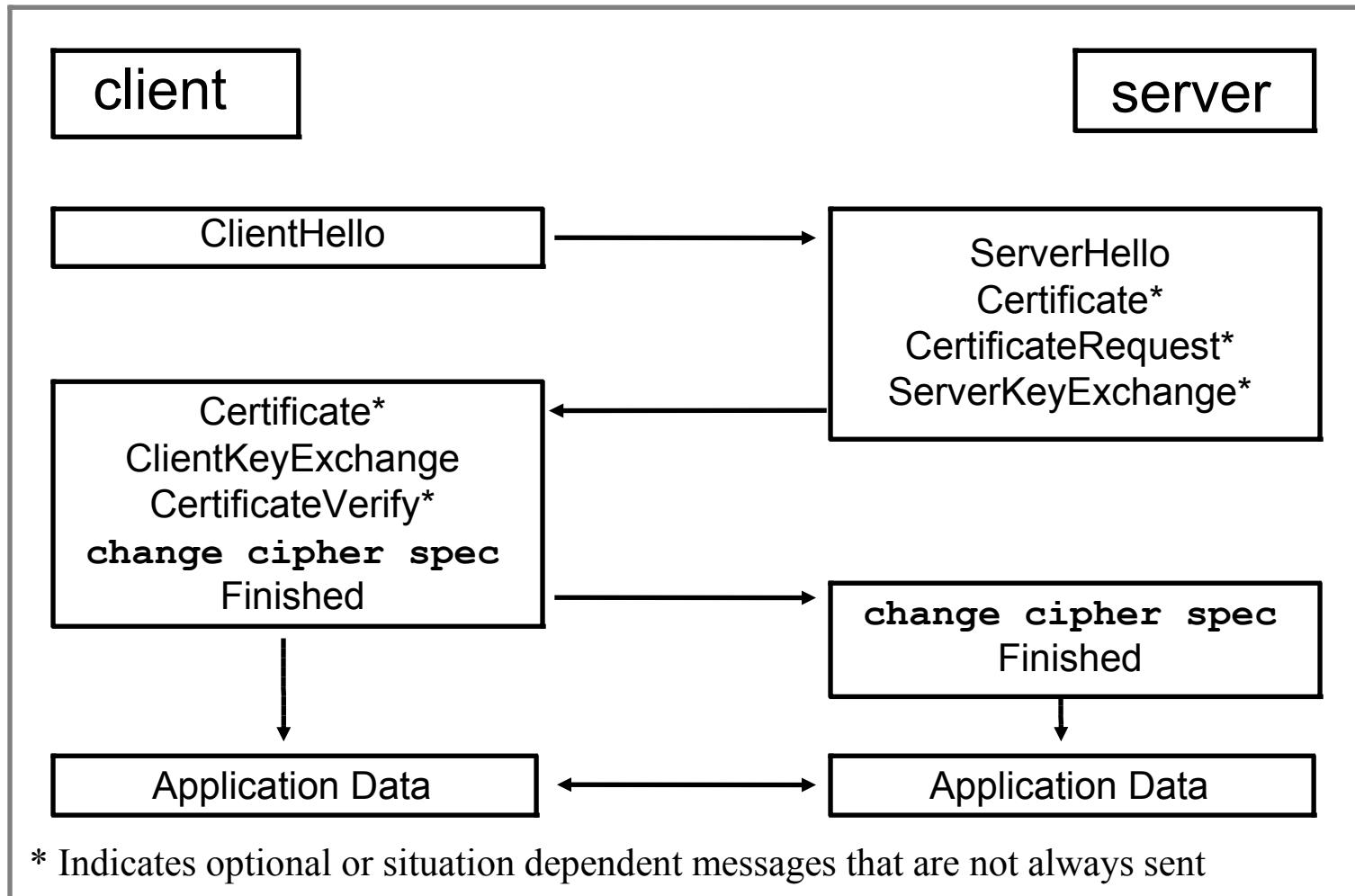


The Handshake Protocol



- 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

Handshake Protocol summary



Computing the 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
- $\text{KeyBlock} = f(\text{MasterSecret}, \text{Client.Random}, \text{Server.Random})$

$\text{KeyBlock} = \text{MD5}(\text{MasterSecret} + \text{SHA}('A' + \text{MasterSecret} + \text{ServerHello.Random} + \text{ClientHello.Random})) +$
 $\text{MD5}(\text{MasterSecret} + \text{SHA}('B' + \text{MasterSecret} + \text{ServerHello.Random} + \text{ClientHello.Random})) +$
 $\text{MD5}(\text{MasterSecret} + \text{SHA}('C' + \text{MasterSecret} + \text{Server.Hello.Random} + \text{ClientHello.Random})) + [...]$

KeyBlock	Client_MAC_Secret
	Server_MAC_Secret
	Client_Key
	Server_Key
	Client_Stream_Key
	Server_Stream_Key

Partition key-stream
into individual
quantities

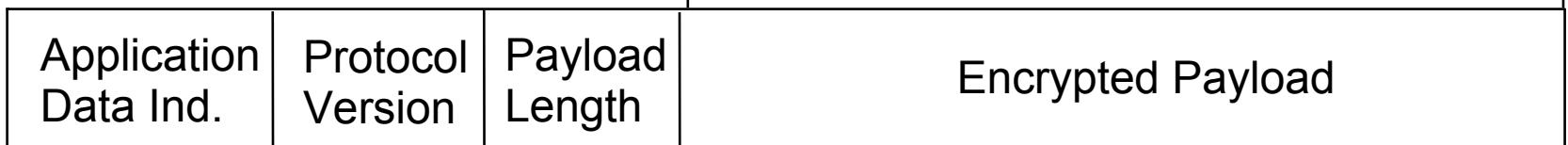
Applying the Keys to Application Data (Record Layer)

Divide stream into blocks

Compress

Compute MAC

Block Cipher (with padding) or
Stream Cipher



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 TLS Handshake Visualisation

<https://tls.nqsb.io/>

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

If you allow JS, you can click the arrows.

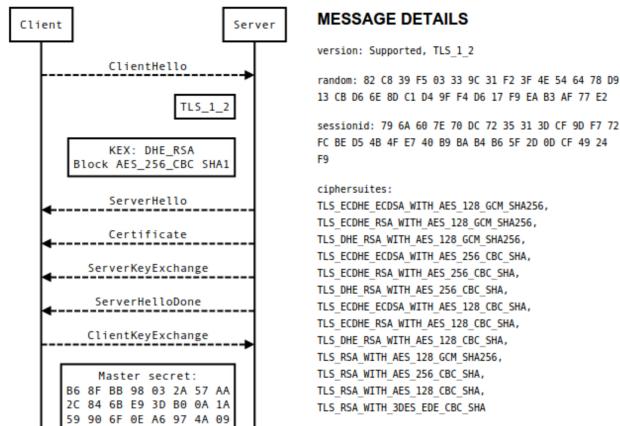
Nice!

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 **).

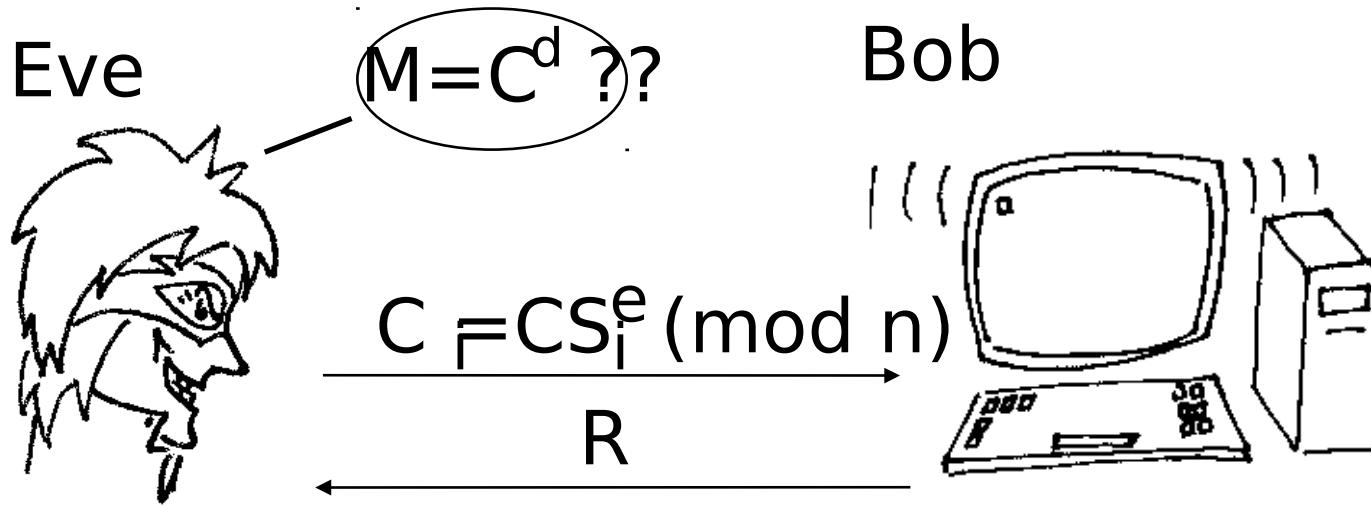
Renegotiate! lets our server send a *Hello Request* message to the client, and JavaScript fetches a new trace and updates the sequence diagram. Our demo server picked a protocol version and ciphersuite at random.



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

$$2^{256^{k-2}} - 1 < MS < 3^{256^{k-2}}$$

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

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: Basically everywhere, Standard part of Web browsers, servers and development platforms (PHP, python etc.)
 - secure online trading, banking, commerce...
- Certificates being issued by a variety of Trusted Third Parties (TTP)
 - VeriSign, Cybertrust/Baltimore OMNIRoot

Recent TLS Developments

- TLS WG no longer in maintenance mode as work on TLS 1.3 nearing completion (more on that later)
- Datagram TLS (DTLS) for use with connectionless applications (e.g. RTP) is RFC 6347
- Much more on all that shortly...

Recent(ish) TLS-relevant Stuff

- IETF dane WG: <http://tools.ietf.org/wg/dane>
TLSA RR: hashes of keys in DNS (4 options)
 - Requires DNSSEC
 - Provide additional assurance that the right key is being used for TLS, or avoids use of CAs
- IETF websec WG:
 - Key-pinning in HTTP (HPKP): RFC 7469
 - Strict Transport Security (HSTS): RFC 6797
- OSCP Stapling (RFCs 6066, 6961)

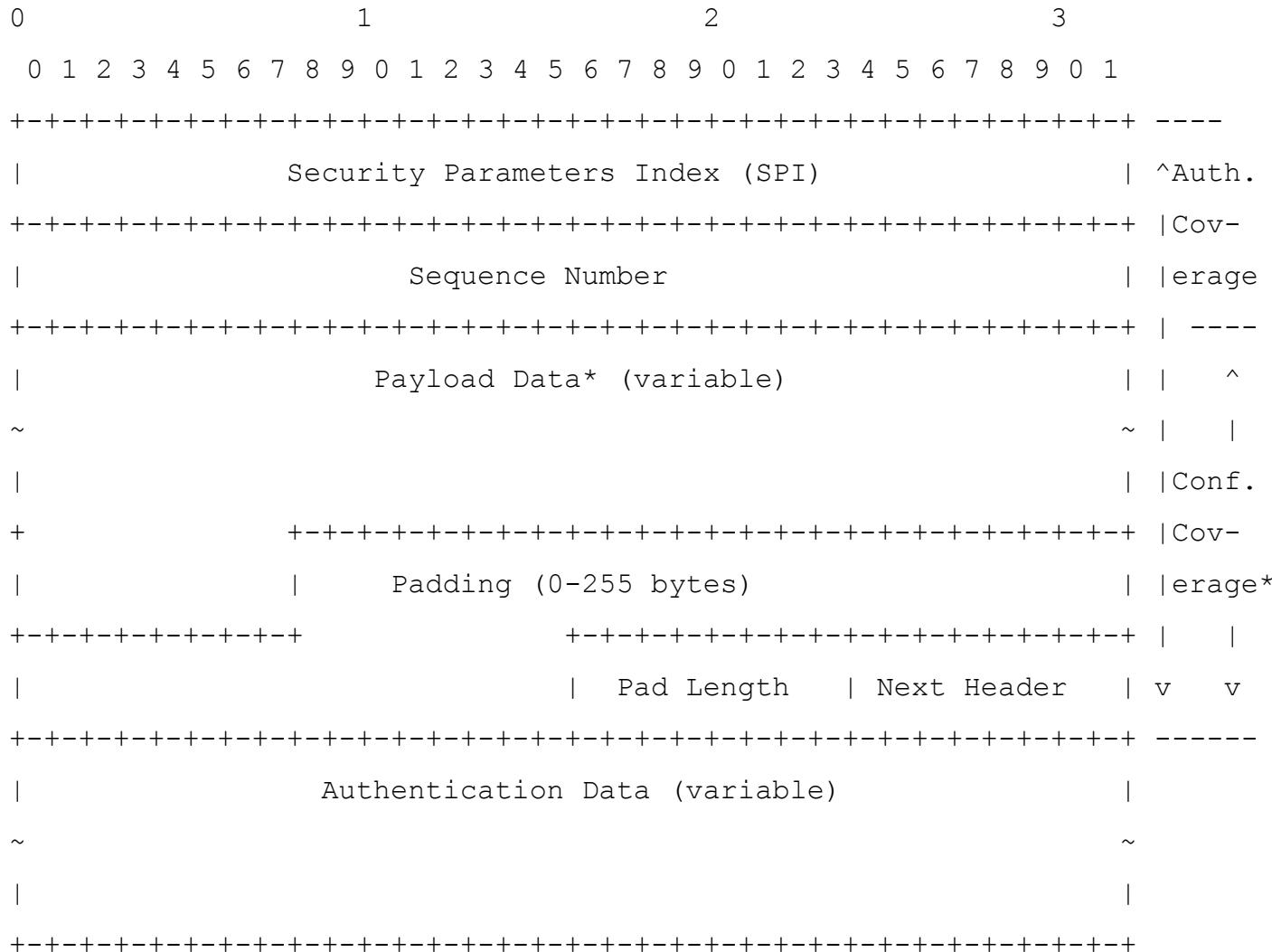
IP Security (Ipsec)

- Took sooooo looooong and produced such a complex outcome that they have a 2011 document roadmap (rfc6071).
- Start with rfc 4301, the security architecture
- Main moving parts: AH (RFC 4302), ESP (RFC 4303), and IKEv2 (RFC 5996)
 - AH mostly deprecated
 - IKE -> IKEv2 due to IKE/ISAKMP/... complexity, do NOT bother with IKEv1
- So, we'll only look at ESP & IKEv2

Ipsec overview

- “Security Architecture” rfc4301
 - 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

ESP - Encapsulated Security Payload



ESP terms

- Specification: rfc4303
- 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 (rfc2409) 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

- Mutually authenticate
 - Exchange keys

- Based on:

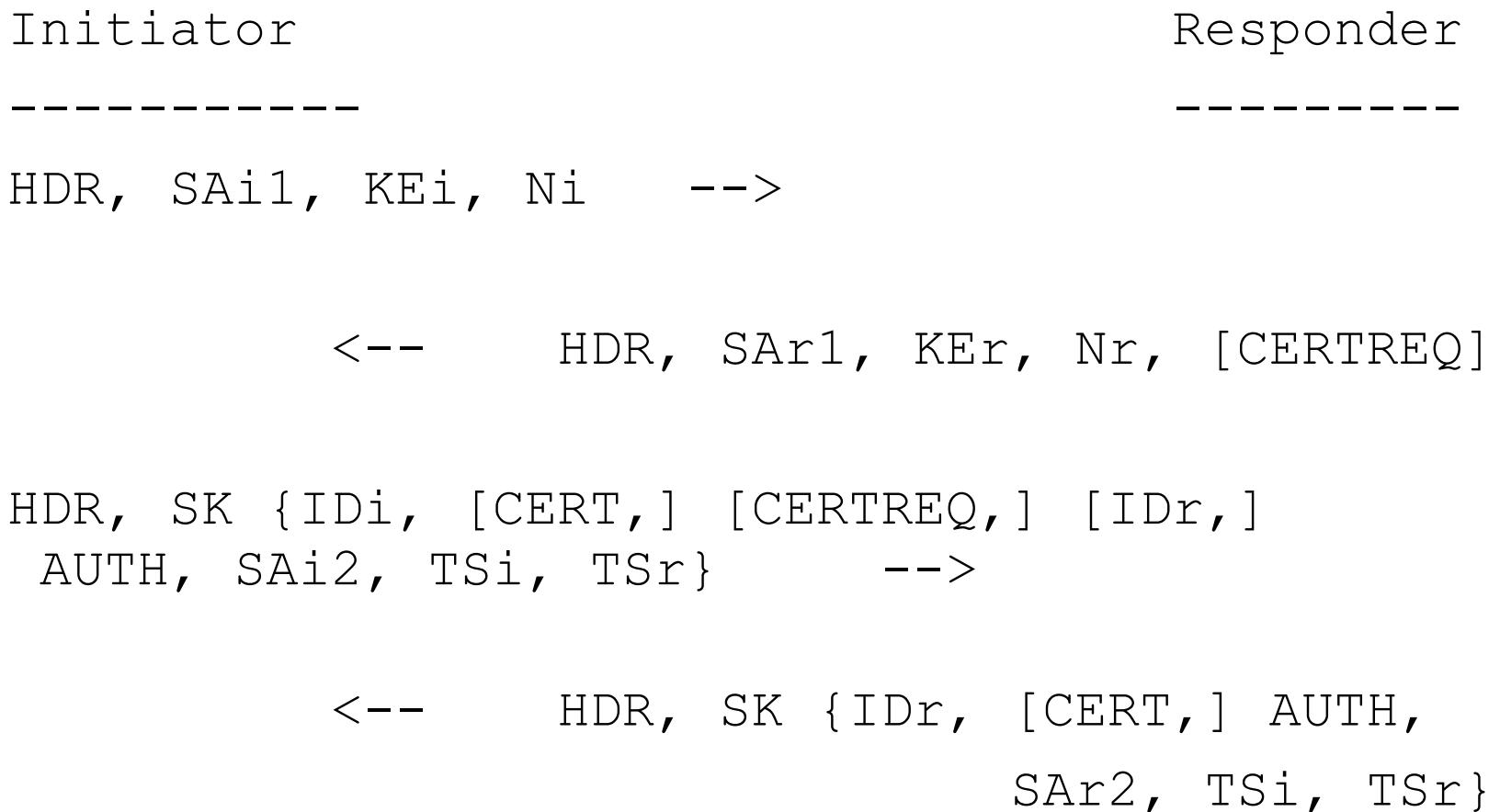
- D-H and
 - Pre-shared secrets or RSA

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



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

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 Things to Note

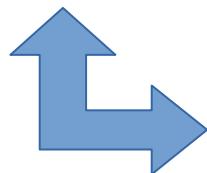
- Loose clock sync. Required
- Kerberos realm is like but not the same as a DNS domain
- Inter-realm and public key based operation defined but not used that often
- Used in Windows NT security and later (KDC is part of ActiveDirectory)
- Various authorization data extension have been done over the years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

Mix'n'match

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

Recent hour(s)...

- PKI model and protocols
- SMIME formats and secure email
- SSL/TLS protocol
- IPsec
- Kerberos



Knowing one of these in detail is enough for exam purposes