IPsec Details

Authentication Header (AH)

- Based on keyed cryptographic hash function.
- Covers AH header, payload and immutable portion of preceeding IP header.
- Not that useful today, compared to ESP with null authentication
- Usually used with HMAC-SHA1 or HMAC-MD5
- HMAC output is frequently truncated
- Details: see RFC 4302

AH Layout

proto	length	reserved
SPI		
Sequence Number		
digest (variable length)		

Other AH Fields

- "Proto" — what transport protocol header is next (i.e., TCP, UDP, etc.)
- "length" — length of AH header in 32-bit words, minus 2
- Actually, length is implicit in the security association; putting it in the header permits context-free (and unkeyed) examination of the packet
- "Sequence" — prevents replay attacks

Mutable Parts of the IP Header

- Some parts of the IP header change in transit
- Obvious: TTL (and hence IP checksum)
- Fragmentation? You generally reassemble fragments before doing AH processing
- DSCP (previously known as ToS)
- IP options — some change in flight (record route, source route); others do not. See RFC 4302 for details

What is an SPI?

- SPI — Security Parameter Index
- Identifies *Security Association*
- Each SA has its own keys, algorithms, policy rules
- On packet receipt, look up SA from ⟨SPI, dstaddr⟩ pair

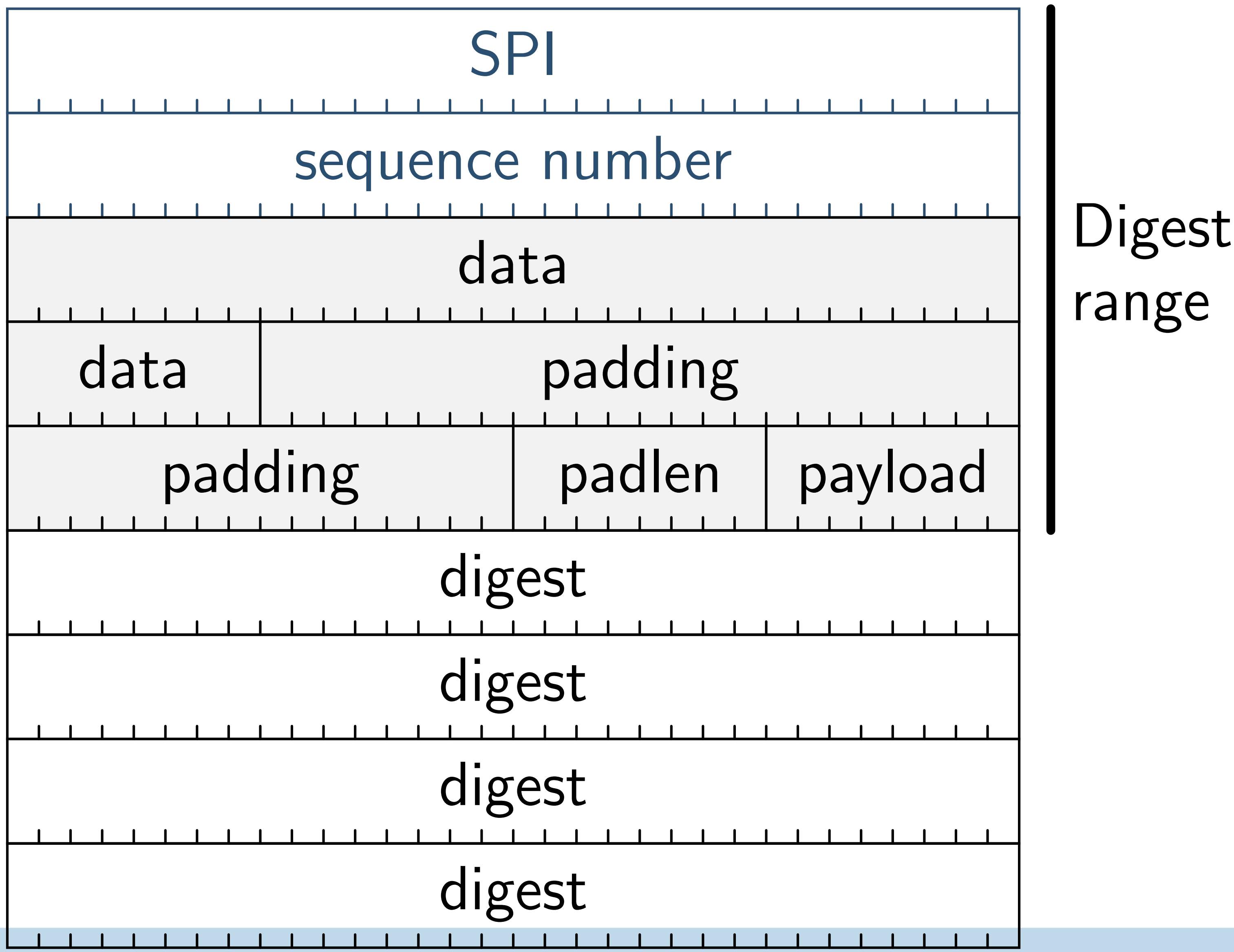
What's an SA?

- SA: *Security Association*
- Think of it as an IPsec connection
- All of the parameters needed for an IPsec session: crypto algorithms (AES, SHA1, etc.), modes of operation (CBC, HMAC, etc.), key lengths, traffic to be protected, etc.
- Both sides must agree on the SA for secure communications to work

Encapsulating Security Payload (ESP)

- Carries encrypted packet.
- An SPI is used, as with AH.
- Preferred use of ESP is for AES in CBC mode with (truncated) HMAC-SHA1 for authentication
- IV, if used, is the first few bytes of "data"
- Older systems use 3DES, perhaps with HMAC-MD5
- Details in RFC 4303

ESP Layout



SPI
sequence number
data
data
padding
padding
padlen
payload
digest
digest
digest
digest
Digest range

Padding

- “padlen” says how many bytes of padding should be removed from the packet
- Primary purpose: handle CBC blocksize issue
- Secondary purpose: add random extra padding, to confuse traffic analysts (but it doesn’t do a very good job of that)

Using ESP

- Can be used with null authentication or null encryption
- With null encryption, provides authentication only
- Easier to implement than AH
- Note: you should *virtually always* use authentication with ESP
- Similarly, sequence numbers should be used whenever possible

IPsec and Firewalls

- Encryption is not authentication or authorization
- Access controls may need to be applied to encrypted traffic, depending on the source.
- The source IP address is only authenticated if it is somehow bound to the certificate.
- Encrypted traffic can use a different firewall; however, co-ordination of policies may be needed.

IPsec and the DNS

- IPsec often relies on the DNS.
  - Users specify hostnames.
  - IPsec operates at the IP layer, where IP addresses are used.
  - An attacker could try to subvert the mapping.
- DNSSEC may not meet some organizational security standards.
- DNSSEC — which isn't deployed yet, either — uses its own certificates, not X.509.

Implementation Issues

- How do applications request cryptographic protection? How do they verify its existence?
- How do adminstrators mandate cryptography between host or network pairs?
- We need to resolve authorization issues.

Key Management Requirements

Why Key Management?

- Where do IPsec keys come from?
- Could we use static keys?
- What are the other requirements for key management?

Static Keys

- In theory, static keys can be used; in practice, they have several disadvantages
- Primary disadvantage: they almost certainly will not be random enough
- (If they're passwords, attackers can launch a password guessing attack)
- History (and theory) suggest that it's a bad idea to encrypt too much plaintext with a single key
- You can't use replay protection with static keys

Replay Protection

- The first packet transmitted on an SA *must* be numbered 1
- Any time a machine reboots and loses knowledge of its sequence number status, it will restart from 1
- Besides, 2^{32} packets isn't that many; it *will* wrap around at some point
- Replays can be used to attack confidentiality

SA Management

- We spoke of the SADB
- How does it get populated?
- We must negotiate it!

Other Issues

- SA lifetime
- Dead peer detection
- SA tear-down
- Algorithm negotiation
- Other negotiations

Internet Key Exchange (IKE)

IKE

- *Very* complex protocol
- Does a lot, probably too much
- We'll just skim the surface, and we'll discuss IKEv2, which is simpler
- I'll be simplifying it, too. . .

Basic Philosophy

- Two parties, *Initiator* and *Responder*
- First set up a *control SA* (known in IKEv1 as a *Phase 1* SA)
- Use the control SA to create *child SAs* (known as *Phase 2* SAs)
- Actual IPsec data is protected via child SAs
- Other control traffic can use the control SA

Initial Exchange

- (Each message includes a random SPI, to distinguish between different IKE sessions.)
- Negotiate cryptographic algorithms
- Do a Diffie-Hellman exchange

$$I \rightarrow R: \quad \mathsf{SA}_i 1, \mathsf{KE}_i, N_i$$
$$R \rightarrow I: \quad \mathsf{SA}_r 1, \mathsf{KE}_r, N_r, [\mathsf{Certreq}]$$

SA	Crypto algorithm proposals and answer
KE	Diffie-Hellman exponential
N	Nonce (random number)
Certreq	List of trust anchors (CAs)

What Do We Have?

- I has proposed several algorithms; R has accepted one of each category
- The two sides have a Diffie-Hellman shared secret. The Diffie-Hellman shared secret is combined with the two nonces to produce *seed keying material*. Any message M protected by keying material derived from this will be written $\boxed{M}$
- Different keys are used in each direction
- I knows what CAs R trusts
- Neither side knows the other's identity yet

Authentication

$$I \rightarrow R: \quad \boxed{\mathsf{ID}_i, \mathsf{SA}_i 2, \mathsf{TS}_i, \mathsf{TS}_r, [\mathsf{Cert}]}, \mathsf{Auth}$$

$$R \rightarrow I: \quad \boxed{\mathsf{ID}_r, \mathsf{SA}_r 2, \mathsf{TS}_i, \mathsf{TS}_r}, \mathsf{Auth}$$

Both sides send their own identities, the SA data for subsequent exchanges, *traffic selectors*, and an *authenticator*.

The authenticator is either an HMAC or a digital signature of the message (including the SPI) concatenated with the current sender's identity and the other party's nonce.

There are various other optional payloads for certificates, CAs, etc.

What Do We Have?

- Both sides know the other's identity
- Both sides have authenticated the other
- Both sides have shared seed key material
- I has proposed a traffic selector; R has accepted a possibly-narrower one

Traffic Selectors

- A *traffic selector* is a list of IP addresses and port numbers that are to be protected by the SA
- TS_i specifies source addresses and ports; TS_r specifies destination addresses and ports
- I proposes a certain range of traffic it wishes to protect
- R may agree to a narrower range
- This lets I — possibly a laptop — have a simple, "protect everything" configuration; the central gateway can narrow the scope of protection if desired

Child SAs

- The control SA can now be used to create child SAs for actual user traffic

$$I \rightarrow R : \boxed{\mathsf{SA}, N_i, [\mathsf{KE}_i], [\mathsf{TS}_i, \mathsf{TS}_r]}$$

$$R \rightarrow I : \boxed{\mathsf{SA}, N_r, [\mathsf{KE}_r], [\mathsf{TS}_i, \mathsf{TS}_r]}$$

- Send new nonces for use in calculating keying material. For greater forward secrecy, send an optional new Diffie-Hellman exponential.
- Optionally negotiate new traffic selectors

Rekeying

- Any SA can be rekeyed
- To rekey an SA, send a Rekey message with an SA identifier, new nonces, and perhaps new Diffie-Hellman exponentials
- Omit traffic selectors

SA Lifetime

- SAs do not have negotiated lifetimes
- When either side thinks an SA has been around for long enough, it negotiates a new SA
- Net effect: SA lifetime is the shorter of the two sides' preferences
- *After* the new one is set up, delete the old SA

Other Control Messages

- IKE “ping” — see if the other side is still alive
- Delete SA
- Obtain a remote IP address
- Check version information
- Error messages

Timeouts

- IKE runs over UDP
- Each side must therefore implement its own timers and retranmissions
- It's reasonable to keep a cache of recently-received and -transmitted messages — when a duplicate request arrives, retransmit the cached copy

Denial of Service

- What if an attacker attempts to exhaust R's CPU time or memory?
- CPU time: force it to calculate many D-H exponentials
- Memory: create initial SAs; don't authenticate them

Defenses

- To prevent CPU time attacks, it's permissible to reuse D-H exponentials for a short while (though it hurts perfect forward secrecy)
- To prevent memory attacks, watch for too many incomplete SAs
- When these start to occur, reject new requests and send a *cookie* instead
- These are stateless, cryptographically sealed messages bound to the sender's IP address
- Require that such a cookie be returned with the actual first message
- Guards against spoofed IP address attacks

Using IKE

- A host is configured with an initial protection SPD
- When a packet is to be sent that matches the SPD, IPsec searches for an existing SA
- If there is none, a request is sent to the local IKE daemon
- The IKE daemon attempts to create an SA, and updates the SAD
- (On some systems, this may result in updating the SPD)
- The packet is then transmitted

Some Attacks

Attacks!

- I keep talking about subtle attacks
- Let's look at some old ones. . .

Splicing Attack

- Suppose that (a) ESP is being used with no authentication, (b) no sequence numbers, and (c) the good guy and the bad guy can send traffic on the same SA
- The bad guy intercepts a good guy's packet, sends a UDP packet with checksums turned off, and intercepts it, too
- The attacker then uses CBC splicing to replace the end of the UDP packet with the good guy's packet, and reinjects it
- The receiving IPsec sees this packet, decrypts it, and passes it to the bad guy's UDP listener

Defenses

- Use ESP authentication
- Use ESP sequence numbers, to prevent reinjection of the UDP packet (though there are other variants that make that less useful)
- Use a separate SA for each connection

Using a Separate SA?

- If you use separate SAs for each connection, it makes life easier for traffic analysts
- It can also aid cryptanalysts

Probable Plaintext Attacks

- How does a cryptanalyst know if a guess at the key was correct?
- What should the packet look like?
- Compare certain fields from two packets for the same connection — they should match
- Source and destination IP address must match exactly
- Probabilistically, most bits of counters (such as TCP sequence numbers) will match: if you add 512 to a 32-bit number, probability is .97 that the high-order 18 bits remain unchanged, and the low-order 9 bits are always unchanged
- Other fields can be matched as well

Defenses

- Not easy!
- Try avoiding per-connection SAs
- Don't use ciphers that are weak enough that this is a useful attack…