UNIVERSITY OF AMSTERDAM

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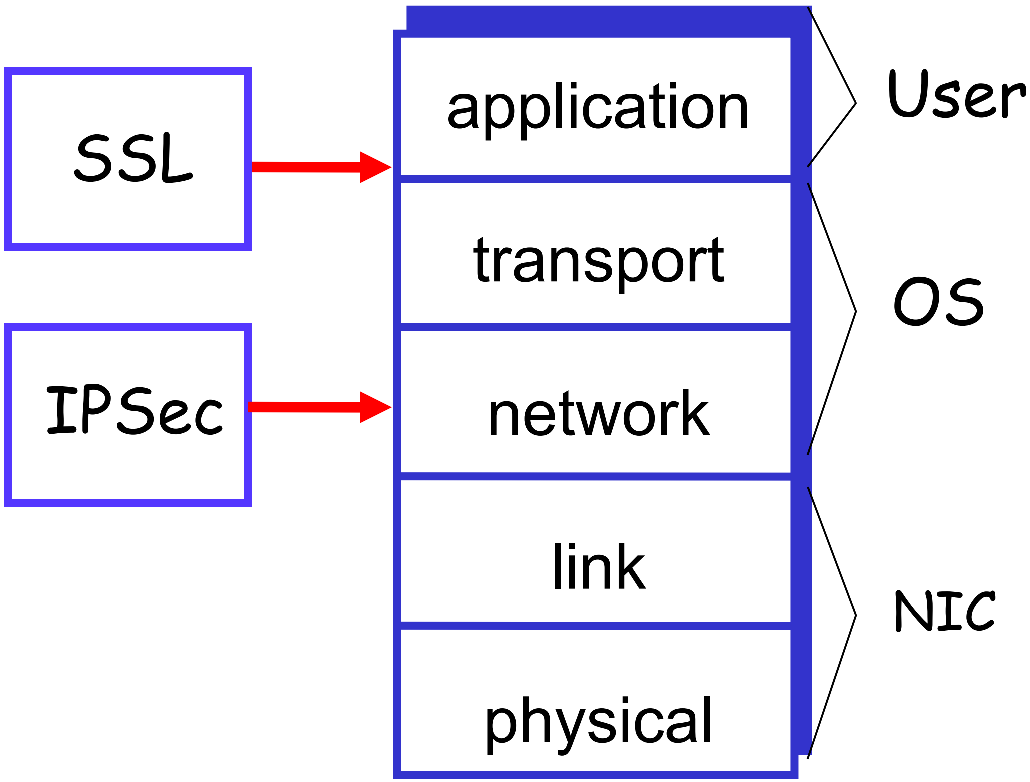
Security of Systems and Networks

October 12, 2019 IPsec

IPSec

IPSec and SSL

- IPSec lives at the network layer
- IPSec is transparent to applications



IPSec and Complexity

- IPSec is a complex protocol
- Over-engineered
  - Lots of generally useless extra features
- Flawed
  - Some serious security flaws
- Interoperability is serious challenge
  - Defeats the purpose of having a standard!
- Complex
- Did I mention, it's complex?

IKE and ESP/AH

- Two parts to IPSec
- **IKE:** Internet Key Exchange
  - Mutual authentication
  - Establish shared symmetric key
  - Two "phases" — like SSL session/connection
- **ESP/AH**
  - ESP: Encapsulating Security Payload — for encryption and/or integrity of IP packets
  - AH: Authentication Header — integrity only

IKE

IKE

- IKE has 2 phases
  - Phase 1 – IKE security association (SA)
  - Phase 2 – AH/ESP security association
- Phase 1 is comparable to SSL session
- Phase 2 is comparable to SSL connection
- Not an obvious need for two phases in IKE
- If multiple Phase 2's do not occur, then it is **more** expensive to have two phases!

IKE Phase 1

- Four different "key" options
  - Public key encryption (original version)
  - Public key encryption (improved version)
  - Public key signature
  - Symmetric key
- For each of these, two different "modes"
  - Main mode
  - Aggressive mode
- **There are 8 versions of IKE Phase 1!**
- Evidence that IPSec is over-engineered?

IKE Phase 1

- We'll discuss 6 of 8 phase 1 variants
  - Public key signatures (main and aggressive modes)
  - Symmetric key (main and aggressive modes)
  - Public key encryption (main and aggressive)
- Why public key encryption and public key signatures?
  - Always know your own private key
  - **May not** (initially) know other side's public key

IKE Phase 1

- Uses ephemeral Diffie-Hellman to establish session key
  - Achieves perfect forward secrecy (PFS)
- Let a be Alice's Diffie-Hellman exponent
- Let b be Bob's Diffie-Hellman exponent
- Let g be generator and p prime
- Recall p and g are public

IKE Phase 1: Digital Signature (Main Mode)

Alice

- Alice → Bob: IC, CP
- Bob → Alice: IC,RC, CS
- Alice → Bob: IC,RC, g^a mod p, R_A
- Bob → Alice: IC,RC, g^b mod p, R_B
- Alice → Bob: IC,RC, E("Alice", proof_A, K)
- Bob → Alice: IC,RC, E("Bob", proof_B, K)

Bob

- CP = crypto proposed, CS = crypto selected
- IC = initiator "cookie", RC = responder "cookie"
- K = h(IC,RC,g^{ab} mod p,R_A,R_B)
- SKEYID = h(R_A, R_B, g^{ab} mod p)
- proof_A = [h(SKEYID,g^a,g^b,IC,RC,CP,"Alice")]$_{\text{Alice}}$

IKE Phase 1: Public Key Signature (Aggressive Mode)

Alice

IC, "Alice", g^a mod p, R_A, CP →

← IC,RC, "Bob", R_B, g^b mod p, CS, proof_B

IC,RC, proof_A →

Bob

- Main difference from main mode
  - Not trying to protect identities
  - Cannot negotiate g or p

Main vs Aggressive Modes

- Main mode **MUST** be implemented
- Aggressive mode **SHOULD** be implemented
  - In other words, if aggressive mode is not implemented, "you should feel guilty about it"
- Might create interoperability issues
- For public key signature authentication
  - Passive attacker knows identities of Alice and Bob in aggressive mode
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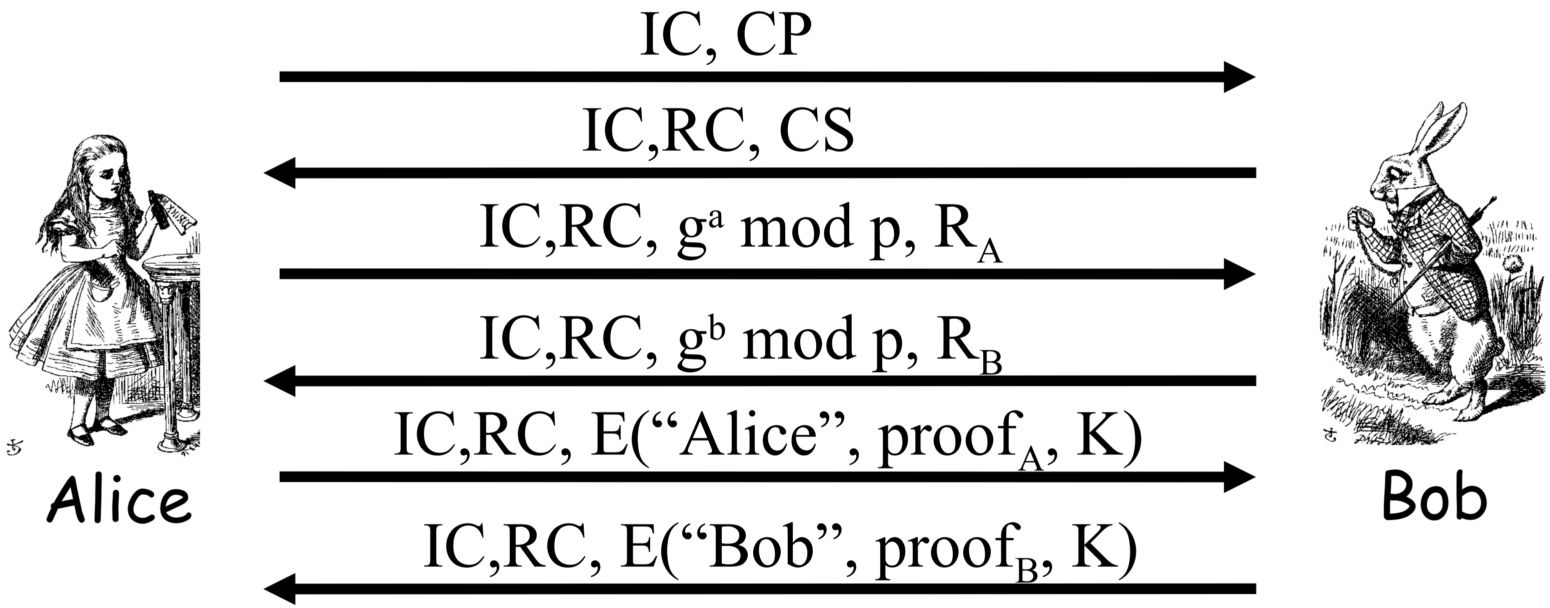
IKE Phase 1: Symmetric Key (Main Mode)



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Problems with Symmetric Key (Main Mode)

- Catch-22
  - Alice sends her ID in message 5
  - Alice's ID encrypted with K
  - To find K Bob must know K_{AB}
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- Result: **Alice's ID must be IP address!**
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- Why go to all of the trouble of trying to hide identities in 6 message protocol?

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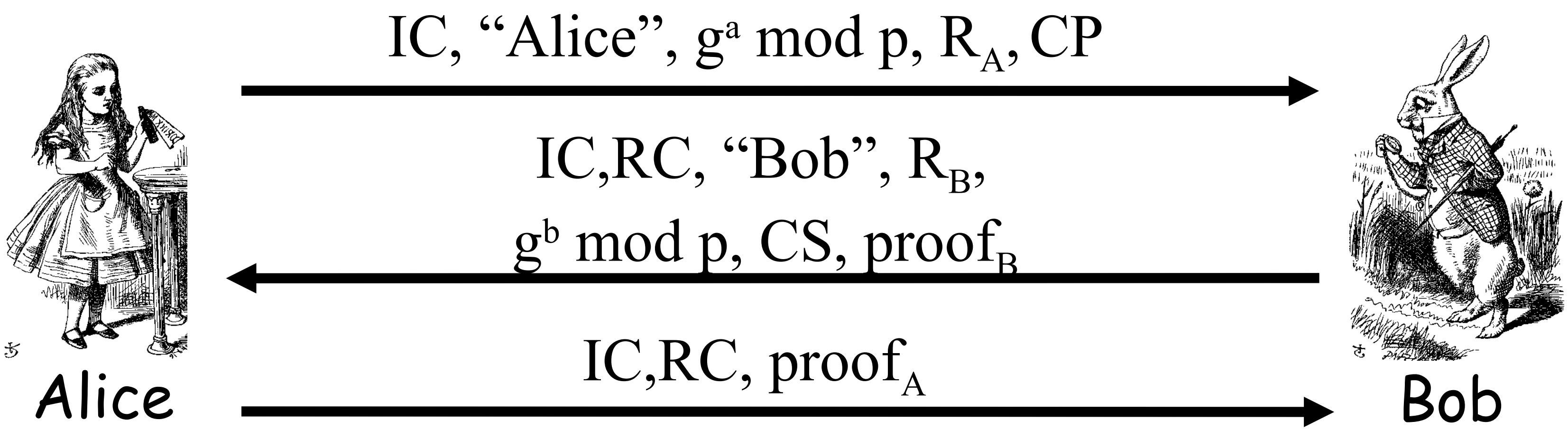

- Same format as digital signature aggressive mode
- Not trying to hide identities…
- As a result, does **not** have problems of main mode
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IKE Phase 1: Public Key Encryption (Main Mode)

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IC, CP →

← IC,RC, CS

IC,RC, g^a mod p, $\{R_A\}_{Bob}$, $\{\text{“Alice”}\}_{Bob}$ →

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$IC, CP, g^a \bmod p, \{\text{“Alice”}\}_{Bob}, \{R_A\}_{Bob}$ →

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- K, $proof_A$, $proof_B$ computed as in main mode
- Note that identities are hidden
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Public Key Encryption Issue?

- Public key encryption, aggressive mode
- Suppose **Trudy** generates
  - Exponents **a** and **b**
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Public Key Encryption Issue?

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IC, CP, $g^a \bmod p$, $\{\text{"Alice"}\}_{Bob}$, $\{R_A\}_{Bob}$ →

← IC,RC, CS, $g^b \bmod p$, $\{\text{"Bob"}\}_{Alice}$, $\{R_B\}_{Alice}$, $proof_B$

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Trudy as Bob

- Trudy can create exchange that appears to be between Alice and Bob
- Appears valid to any observer, **including Alice and Bob!**

Plausible Deniability

- Trudy can create "conversation" that appears to be between Alice and Bob
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- In this mode of IPSec, it is a feature
  - **Plausible deniability:** Alice and Bob can deny that any conversation took place!
- In some cases it might be a security failure
  - If Alice makes a purchase from Bob, she could later repudiate it (unless she had signed)

IKE Phase 1 Cookies

- Cookies (or "anti-clogging tokens") supposed to make denial of service more difficult
- No relation to Web cookies
- To reduce DoS, Bob wants to remain stateless as long as possible
- But Bob must remember CP from message 1 (required for proof of identity in message 6)
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IKE Phase 1 Summary

- Result of IKE phase 1 is
  - Mutual authentication
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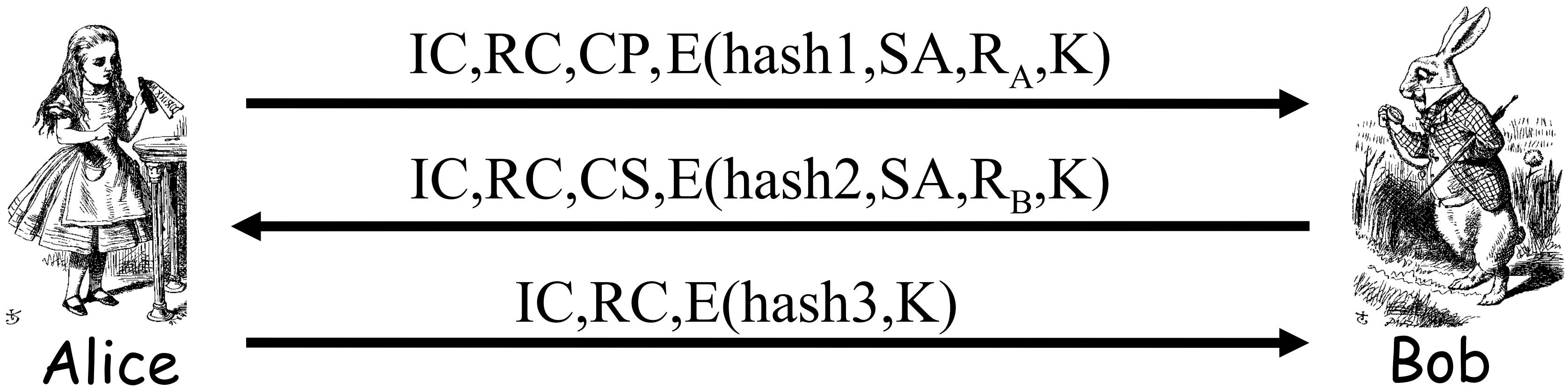
  - IKE **Security Association (SA)**
- But phase 1 is expensive (in public key and/or main mode cases)
- Developers of IKE thought it would be used for lots of things — not just IPSec
- Partly explains over-engineering…

IKE Phase 2

- Phase 1 establishes IKE SA
- Phase 2 establishes IPSec SA
- Comparison to SSL
  - SSL session is comparable to IKE Phase 1
  - SSL connections are like IKE Phase 2
- IKE **could** be used for lots of things
- But in practice, it's **not!**

IKE Phase 2



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- Proposal CP includes ESP and/or AH
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- Keys derived from KEYMAT = h(SKEYID,R_A,R_B,junk)
- Recall SKEYID depends on phase 1 key method
- Optional PFS (ephemeral Diffie-Hellman exchange)

IPSec

- After IKE Phase 1, we have an IKE SA
- After IKE Phase 2, we have an IPSec SA
- Both sides have a shared symmetric key
- Now what?
  - We want to protect IP datagrams
- But what is an IP datagram?
  - From the perspective of IPSec…

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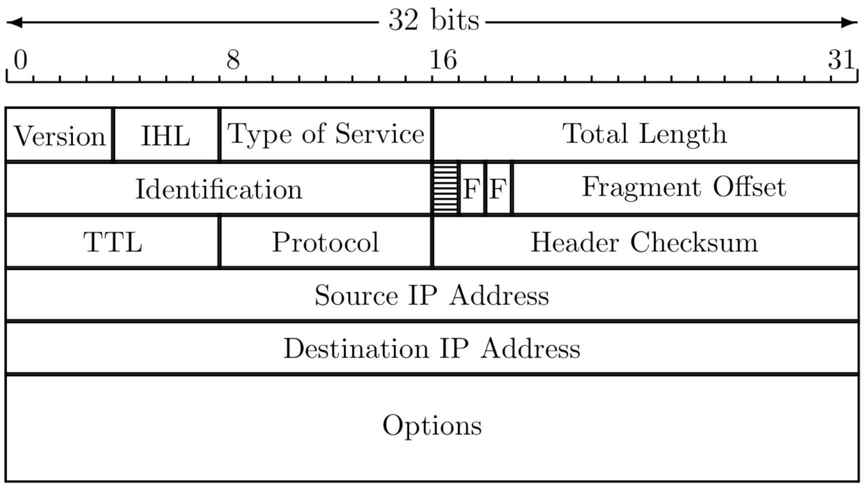
- IP datagram is of the form

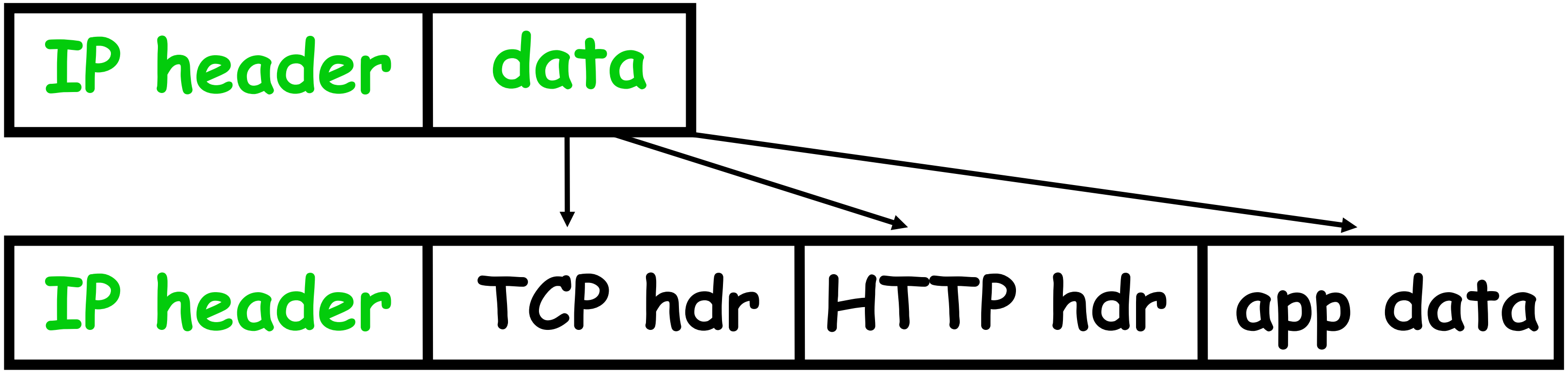
IP header	data

- Where IP header is



IP and TCP

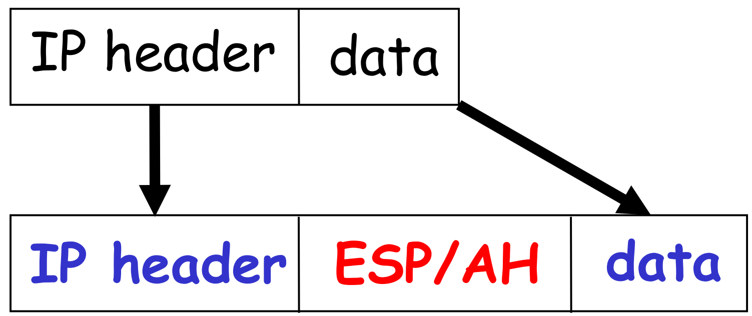
- Consider HTTP traffic (over TCP)
- IP encapsulates TCP
- TCP encapsulates HTTP



- IP data includes TCP header, etc.

IPSec Transport Mode

- IPSec **Transport Mode**



- Transport mode designed for host-to-host
- Transport mode is efficient
  - Adds minimal amount of extra header
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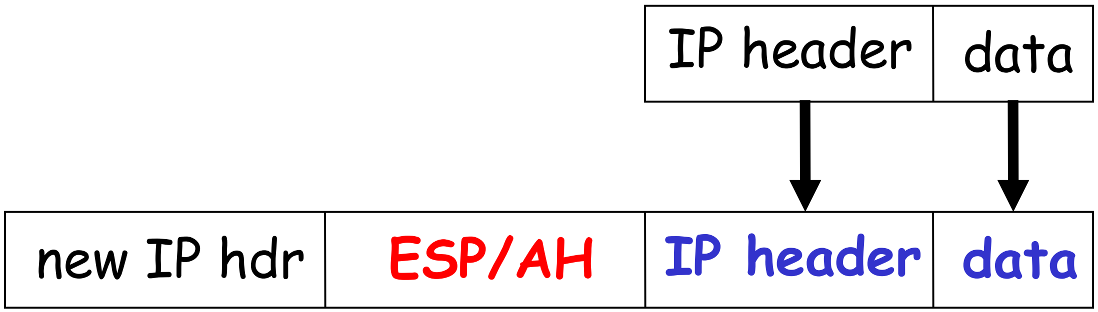
IPSec Tunnel Mode

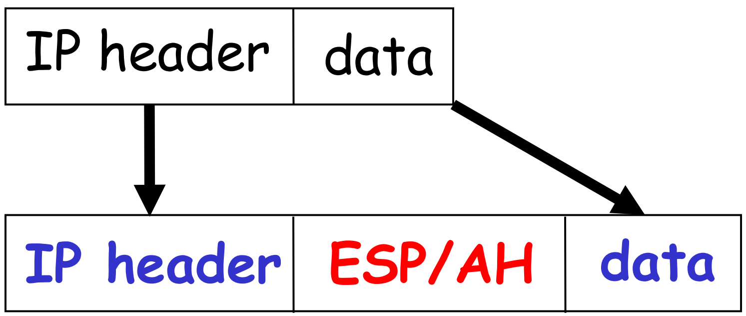
- IPSec **Tunnel Mode**



- Tunnel mode for firewall to firewall traffic
- Original IP packet encapsulated in IPSec
- Original IP header not visible to attacker
  - New header from firewall to firewall
  - Attacker does not know which hosts are talking

Comparison of IPSec Modes

- Transport Mode



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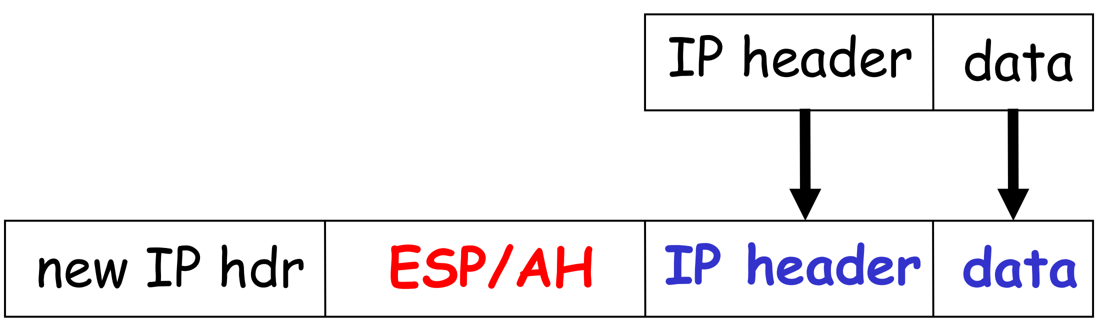

- Transport Mode
  - Host-to-host
- Tunnel Mode
  - Firewall-to-firewall
- Transport mode not necessary
- Transport mode is more efficient

IPSec Security

- What kind of protection?
  - Confidentiality?
  - Integrity?
  - Both?
- What to protect?
  - Data?
  - Header?
  - Both?
- ESP/AH do some combinations of these

AH vs ESP

- AH
  - Authentication Header
  - **Integrity only** (no confidentiality)
  - Integrity-protect everything beyond IP header and some fields of header (why not all fields?)
- ESP
  - Encapsulating Security Payload
  - **Integrity and confidentiality**
  - Protects everything beyond IP header
  - Integrity only by using NULL encryption

ESP's NULL Encryption

- According to RFC 2410
  - NULL encryption "is a block cipher the origins of which appear to be lost in antiquity"
  - "Despite rumors", there is no evidence that NSA "suppressed publication of this algorithm"
  - Evidence suggests it was developed in Roman times as exportable version of Caesar's cipher
  - Can make use of keys of varying length
  - No IV is required
  - Null(P,K) = P for any P and any key K
- Security people have a strange sense of humor!

Why Does AH Exist? (1)

- Cannot encrypt IP header
  - Routers must look at the IP header
  - IP addresses, TTL, etc.
  - IP header exists to route packets!
- AH protects **immutable fields** in IP header
  - Cannot integrity protect all header fields
  - TTL, for example, must change
- ESP does not protect IP header at all

Why Does AH Exist? (2)

- ESP encrypts everything beyond the IP header (if non-null encryption)
- If ESP encrypted, firewall cannot look at TCP header (e.g., port numbers)
- Why not use ESP with null encryption?
  - Firewall sees ESP header, but does not know whether null encryption is used
  - End systems know, but **not** firewalls
- Aside 1: Do firewalls reduce security?
- Aside 2: Is IPSec compatible with NAT?

Why Does AH Exist? (3)

- The real reason why AH exists
  - At one IETF meeting "someone from Microsoft gave an impassioned speech about how AH was useless..."
  - "...everyone in the room looked around and said `Hmm. He's right, and we hate AH also, but if it annoys Microsoft let's leave it in since we hate Microsoft more than we hate AH."

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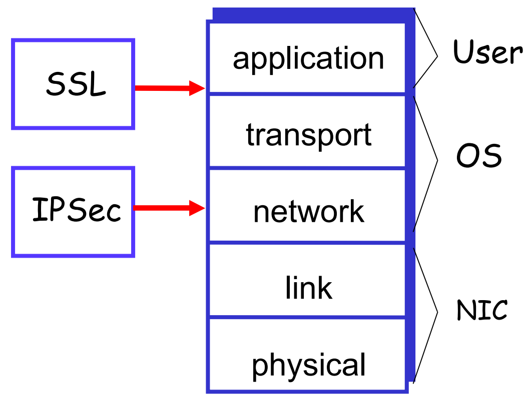

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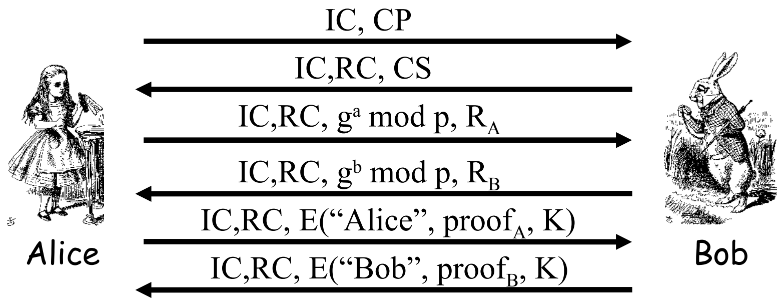

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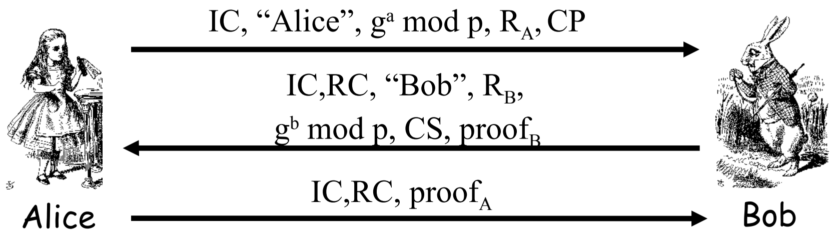

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Main vs Aggressive Modes

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Problems with Symmetric Key (Main Mode)

- Catch-22
  - Alice sends her ID in message 5
  - Alice's ID encrypted with K
  - To find K Bob must know K_{AB}
  - To get K_{AB} Bob must know he's talking to Alice!
- Result: **Alice's ID must be IP address!**
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- Why go to all of the trouble of trying to hide identities in 6 message protocol?

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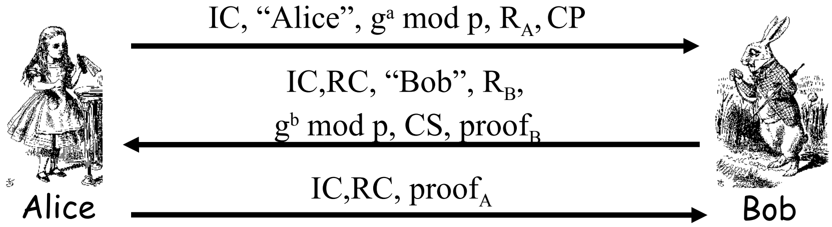

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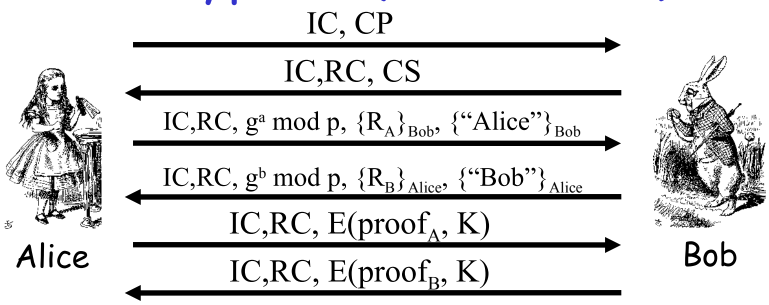

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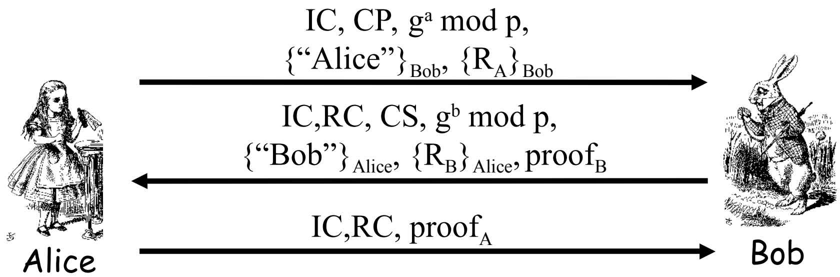

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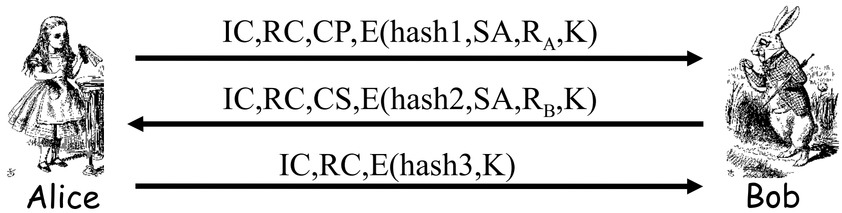

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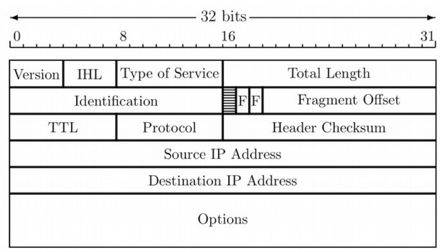
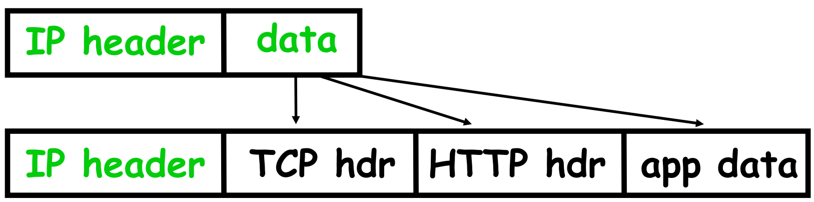


IP and TCP

- Consider HTTP traffic (over TCP)
- IP encapsulates TCP
- TCP encapsulates HTTP



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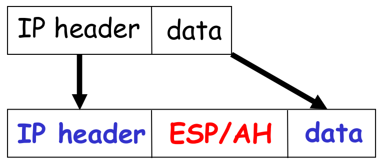
- IPSec **Transport Mode**



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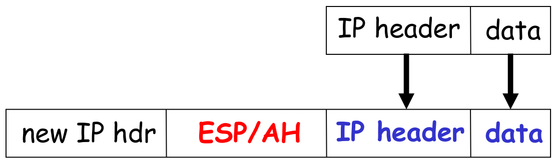
IPSec Tunnel Mode

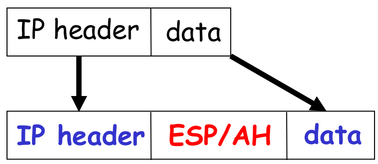
- IPSec **Tunnel Mode**



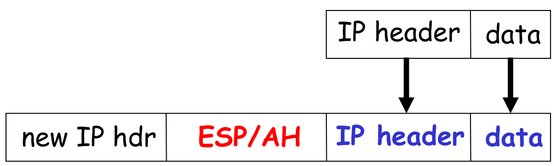
- Tunnel mode for firewall to firewall traffic
- Original IP packet encapsulated in IPSec
- Original IP header not visible to attacker
  - New header from firewall to firewall
  - Attacker does not know which hosts are talking

Comparison of IPSec Modes

- Transport Mode



- Tunnel Mode



- Transport Mode
  - Host-to-host
- Tunnel Mode
  - Firewall-to-firewall
- Transport mode not necessary
- Transport mode is more efficient

IPSec Security

- What kind of protection?
  - Confidentiality?
  - Integrity?
  - Both?
- What to protect?
  - Data?
  - Header?
  - Both?
- ESP/AH do some combinations of these

AH vs ESP

- AH
  - Authentication Header
  - **Integrity only** (no confidentiality)
  - Integrity-protect everything beyond IP header and some fields of header (why not all fields?)
- ESP
  - Encapsulating Security Payload
  - **Integrity and confidentiality**
  - Protects everything beyond IP header
  - Integrity only by using NULL encryption

ESP's NULL Encryption

- According to RFC 2410
  - NULL encryption "is a block cipher the origins of which appear to be lost in antiquity"
  - "Despite rumors", there is no evidence that NSA "suppressed publication of this algorithm"
  - Evidence suggests it was developed in Roman times as exportable version of Caesar's cipher
  - Can make use of keys of varying length
  - No IV is required
  - Null(P,K) = P for any P and any key K
- Security people have a strange sense of humor!

Why Does AH Exist? (1)

- Cannot encrypt IP header
  - Routers must look at the IP header
  - IP addresses, TTL, etc.
  - IP header exists to route packets!
- AH protects **immutable fields** in IP header
  - Cannot integrity protect all header fields
  - TTL, for example, must change
- ESP does not protect IP header at all

Why Does AH Exist? (2)

- ESP encrypts everything beyond the IP header (if non-null encryption)
- If ESP encrypted, firewall cannot look at TCP header (e.g., port numbers)
- Why not use ESP with null encryption?
  - Firewall sees ESP header, but does not know whether null encryption is used
  - End systems know, but **not** firewalls
- Aside 1: Do firewalls reduce security?
- Aside 2: Is IPSec compatible with NAT?

Why Does AH Exist? (3)

- The real reason why AH exists
  - At one IETF meeting "someone from Microsoft gave an impassioned speech about how AH was useless…"
  - "…everyone in the room looked around and said `Hmm. He's right, and we hate AH also, but if it annoys Microsoft let's leave it in since we hate Microsoft more than we hate AH."