Advanced Networking

IPsec
Security Architecture for IP

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based on slides from Prof. Giuseppe Bianchi

Topics

- **Overview of security services**
  - Based on ISO OSI security reference model
- **How some known protocols map to the ISO OSI model?**
  - To layers
  - To security model
- **IPsec**
  - Introduction (operation modes)
  - Architecture (much more than a protocol)
  - protocols (ESP, AH)
  - Management (SAD, SPD)
  - Signaling (IKE)
- **VPN**

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Networking & Security

Security services as defined by ISO

- Defined in the same set of standards as the famous ISO OSI 7 layers (ISO 7498-1) (*1984*)
- ISO 7498-2 OSI Basic Reference Model Part 2: Security Architecture (*1989*)
  - Security **services**: what to do
  - Security **mechanism**: how to achieve it
  - **Mapping** between services and mechanisms
  - Potential **mapping** to 7 layers: where to implement

Further reading: ISO 7498-2 in not free, but you can download free equivalent from ITU as ITU-T X.800

Security Services (what?)

Authentication
- To know who it is: the process of **proving** identity
  - Mutual: both parties identified
  - One-way: only one side proves identity

Access control
- Control access rights to a resource (communication; read/write/delete of data)
  - Good authentication is a pre-condition!

Data confidentiality
- protection of data from unauthorized disclosure

Data integrity
- Preventing/detecting modification of the data

Non-repudiation
- Preventing an individual or entity from denying having performed a particular action
- The recipient of data is provided with proof of the origin of data
- The sender of data is provided with proof of delivery of data.

Security Mechanisms (how?)

Some examples only!

- **Encryption**
  - symmetric key cryptography
    - knowledge of the encryption key implies knowledge of the decryption key and vice versa;
  - asymmetric (or "public") key cryptography
    - knowledge of the decryption key (public key) does not imply knowledge of the encryption key (private key).

  Used in: mainly in confidentiality, but also in authentication

- **Digital signatures**

  Used in: authentication, data integrity, non-repudiation

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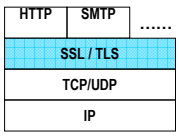
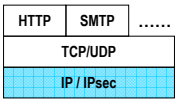
Protocols you might use (or know) layer 3 and above

- **SSL/TLS over TCP**
  - Layer: 4+ (above TCP)
  - Security services:
    - Authentication (mutual / one-way)
    - Data confidentiality
    - Data integrity



- **IPsec**
  - Layer: 3
  - Security services:
    - Authentication (mutual)
    - Access control
    - Data confidentiality
    - Data integrity



Protocols you might use (or know) layer 1,2

Wired

➔ physical protection of the wire!

Wireless

➔ WEP (Wired Equivalent Privacy)

- ⇨ Layer: 2
- ⇨ Security services:
  - → Authentication (weak)
  - → Data confidentiality (weak)
  - → Data integrity (weak)

➔ 802.1x (port-based Network Access Control)

- ⇨ "port" is the LAN port (not the TCP/UDP one)
- ⇨ Layer: 2
- ⇨ Security services:
  - → Access control

SSL/TLS: why layer 4

Network layer security

Transport layer security

😑 TLS is transparent for routers

- ⇨ It operates over TCP … well above IP
  - → IP header is the same => IP routing is not affected
  - → The TCP stream is encrypted, but a router should not look at that
  - → There are some port numbers typically used with TLS, but this is not mandatory (443:https, 993:imaps)

😊 TLS is implemented above Layer 4, in the application

- ⇨ No need to change the OS => fast deployment
  - → Early versions (1994) came as part of Netscape browser
- ⇨ Easy to come up with new modified versions
  - → Dangerous for security protocols!

☹ TLS relies on TCP's reliable stream delivery service

- ⇨ What about security for applications using UDP?
- ⇨ What about other protocols over IP?

☹ Each application should be changed

IPsec: why layer 3

Network layer security

Transport layer security

😊 IPsec is transparent for routers

- ⇨ IPsec operates within (as an upper sub-layer of) layer 3
  - → Uses extension header mechanism: seen by routers as "next protocol" in IP header
  - → packets are routed just as plain IP packets

😊 Applications/terminals unaware of IPsec

- ⇨ IPsec can protect all protocols that rely on IP (but it is hard to differentiate between applications, only TCP/UDP port based differentiation)
- ⇨ It can protect the traffic of whole subnets (tunnel mode, VPN)

☹ Works only if IP routing works

- ⇨ Has difficulties passing NAT/NAPT
- ⇨ Not suitable if application level (e.g. HTTP) proxies are used

☹ Should be implemented in layer 3

- ⇨ In the kernel of the operating system, not in the application

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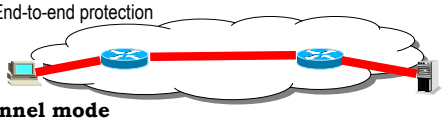
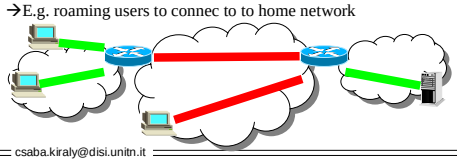
IPsec operation modes

- **Transport mode**
  - End-to-end protection



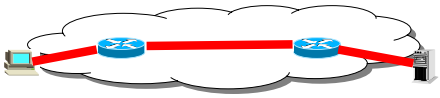
- **Tunnel mode**
  - Security gateway to Security gateway protection
    - E.g. to connect corporate sites
  - Host to Security gateway protection
    - E.g. roaming users to connec to to home network

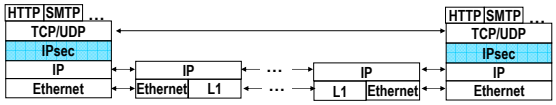


IPsec operation modes

➔**Transport mode**

⇨End-to-end protection

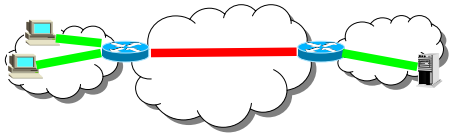




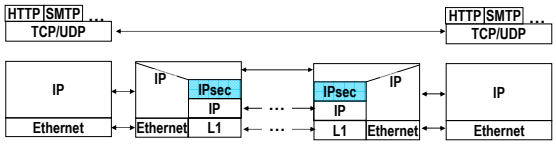
IPsec operation modes

➔**Tunnel mode**

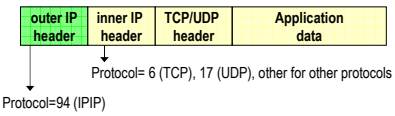
⇨Security gateway to Security gateway protection



⇨protocol stacking with IP-in-IP tunneling



IP-in-IP tunneling



➔ **Encapsulate an IP packet in an IP packet**

⇨ IP can encapsulate other PDUs, not just TCP/UDP/ICMP

⇨ Why not IP itself?

⇨ the "protocol" field should be filled: 94=IPIP

➔ **Routing is done based on the outer header's destination IP**

⇨ Internal IP header is not checked by routers

⇨ Protocol field not used in routing (firewalls are problematic)

➔ **Once this IP packet arrives to its destination (outer), the internal IP packet is decapsulated**

⇨ Routing can continue based on internal destination IP

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  - protocols (ESP, AH)
  - Management (SAD, SPD)
  - Signaling (IKE)
  - History (RFC series)

IPsec: Security Architecture for IP

- **IPsec is not a protocol, but a complete architecture!**
  Components:
  1. Security Protocols (ESP, AH), each having different
     - Protocol header
     - Implemented security mechanisms
     - Provided security services
  2. Cryptographic Algorithms (3DES, etc.)
     - Used by security protocols
     - Each having advantages/disadvantages, e.g.
       - Computational complexity
       - Block size
  3. Management concepts and local management databases
     - Security Policies (SP):
       - established and maintained by a user or system administrator
       - select IP packets where IPsec should be applied
     - Security Associations (SA):
       - simplex "connection" that affords security services to the traffic carried by it
  4. Signaling protocols
     - Internet Key Exchange (IKEv2)

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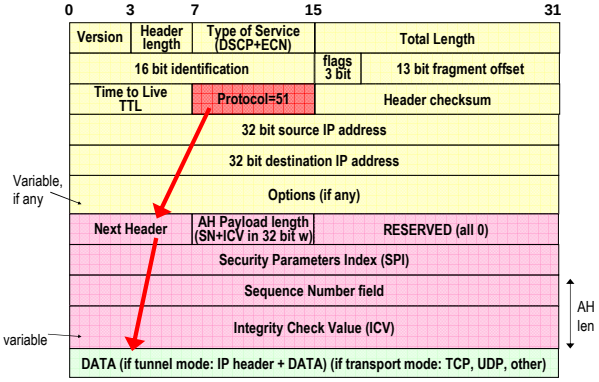
IPsec Security Protocols AH,ESP

(discuss IPv4 only)

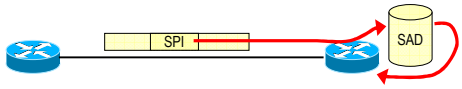
Services provided

- **AH: Authentication Header**
  - Data integrity protection and data origin authentication
    - Covers both payload and parts of IP header that do not modify in transfer
  - Protection against replays
    - Optional, through extended sequence numbers
- **ESP: Encapsulated Security Payload**
  - Same services as AH
    - authentication limited to IP payload only!
  - Confidentiality through encryption
  - Traffic flow confidentiality
    - Improved privacy against eavesdropping
    - Through padding and dummy traffic generation

Authentication Header



Security Parameters Index



- **32 bit index**
- **Role: like port number in TCP and UDP**
- **Used to lookup the SAD at destination**
  - Lookup also uses
    - destination address
    - source address
    - security protocol (AH/ESP)
- **Retrieves algorithms and parameters that allow to process received packet**

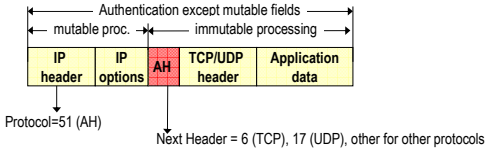
Integrity Check Value computation

- **Only on immutable fields in the IP header**
  - Or mutable but predictable
    - e.g. destination address with strict/loose source routing option
- **Mutable fields set to 0 during ICV computation**
  - Highlighted in red in next figure
    - Note: AH apply before fragmentation, and checked after reassembly
- **Options classified as either mutable or not**
    - Mutable options: details in appendix A RFC 4302
    - mutable options = all zeroed

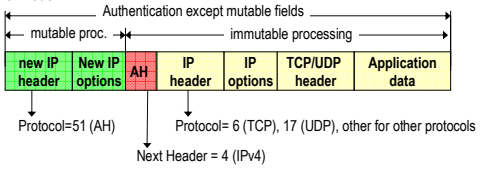
Version	Header length	Type of Service (DSCP+ECN)	Total Length
16 bit identification		flags 3 bit	13 bit fragment offset
Time to Live TTL	Protocol=51 (AH)		Header checksum
32 bit source IP address			
32 bit destination IP address			

Transport mode, tunnel mode

Transport mode:



Tunnel mode:



Why sequence number?

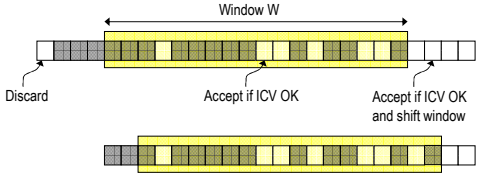
- **IP header DOES NOT contain a sequence number!**
  - Hence replay of an authenticated IP packet is possible
    - And may alter in an unpredictable manner the overlaying service (e.g. ICMP replies can be dangerous ☺)
- **Sequence number: 32 bit counter**
  - Initialized to 0 when the Security Association is established
  - Increments of 1 per each transmitted packet
    - First transmitted packet: SN=1
  - Maximum value 2^{32}-1, afterwards Security Association must be terminated
    - No counter cycling allowed when anti-replay service active
    - Anti-replay: optional (but default = on)
      - » Anti-replay typically OFF when manual (static) keys configured

Extended Sequence Number

- **2^{32} ~ 4.3 billion**
  - A lot, but not REALLY al lot!
    - Packet size = 1500 (1460 bytes payload)
    - 2^{32} x 1460 bytes = 6270 GB
    - About 14 h transmission of a 1 Gbps link
- **Extended Sequence Number:**
  - 64 bits - this should be enough, now ☺
  - Transmit only low order 32 bits
  - But use high order 32 bits in ICV computation!

Anti-replay

- **Sliding Window W**
  - Size locally decided at receiver
    - Minimum = 32; default = 64; higher values recommended for high speed links
    - eventually very large: maximum 2^{31}-1 with SN and 2^{32}-1 with ESN
  - Window right margin = highest NS packet received
- **Duplicates discarded**
- **Packets out of left window edge discarded**
- **Packets greater than right window margin make W shift**



ESP
Encapsulated Security Payload

Encapsulated Security Payload

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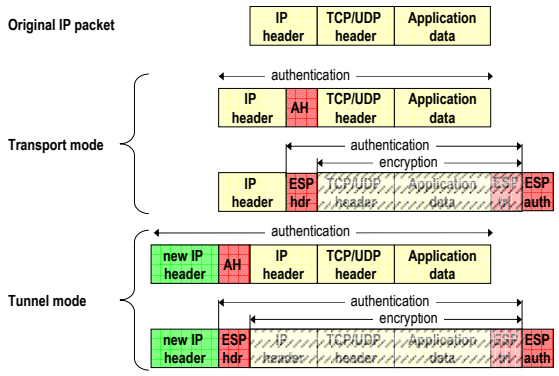
Transport vs Tunnel – AH and ESP



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IPsec management

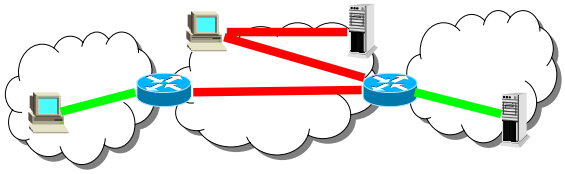
SA: Security Association
SAD: SA Database

SP: Security Policy
SPD: SP Database

SPI: Security Parameters Index

Security Association (SA)

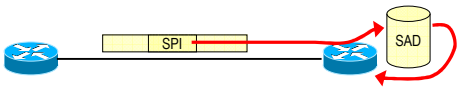
- **Fundamental concept in IPsec**
- **May involve:**
  - Host to host
  - Host to intermediate router (security gateways)
  - Security gateway to security gateway
- **Defines the boundaries for IP packets authentication/encryption**
  - A "connection" with active security services



SA: unidirectional!

- **SPI = Security Parameters Index**
  - The (somewhat) unique "name" of an SA
- **SAD = Security Associations Database**
  - SPI = search key (at least)
  - Stores type of security protocol per each SA, with related parameters
    - E.g. which encryption algorithm; shared key for encryption, SA lifetime, Sequence number counter, etc.
  - SA should be in SAD on both sides, at sender and at receiver!

Security Parameters Index



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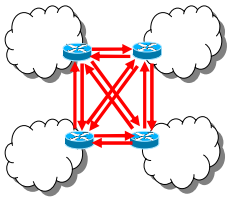
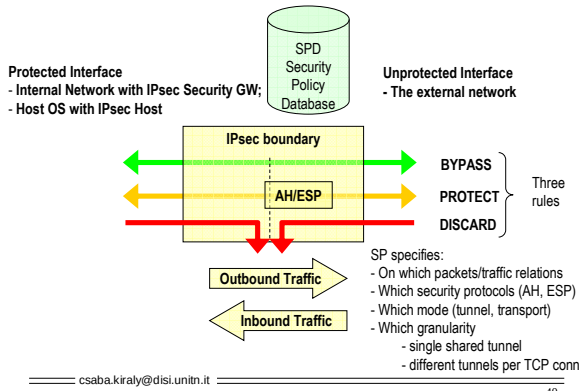
Security Association and Key management

- **Manual**
  - Manually configure each SA and related crypto keys
    - static, symmetric
  - Typical in small-scale VPNs
    - Few security gateways, e.g. one per site
    - Meshed SA connections
- **Automatic**
  - SA management through IKEv2
  - On-demand SA creation
  - Session-oriented keying/rekeying



IPsec protection & access control



IPsec processing

1. **PDU enters IPsec processing: two posibilities**
   - ⇨ Host: PDU from upper layer arrives, or
   - ⇨ Security GW: IP packet arrives
2. **SPD searched for matching SP**
   - ⇨ Search based on IP addresses, higher layer protocol, port number, etc.
3. **If SP found:**
   - a) If BYPASS: no IPsec processing needed
   - b) If DISCARD: PDU dropped (like in a firewall)
   - c) If PROTECT: we know that we have to protect, but we don't know how! It is defined in an SA. Search for corresponding SA in SAD
4. **If SA found, apply it**
   - ⇨ Encapsulate in ESP or AH, with the parameters of the SA
   - ⇨ Encapsulate in IP if tunnel mode
5. **Send protected packet**

IPsec processing

What happens If SP is not found?

⇨No problem, IPsec treatment not needed

⇨PDU goes as it would go otherwise

What happens If SA is not found?

⇨That is a problem: packet must be protected, but we don't know how

⇨SA should be negotiated with other side

⇨Automatic keying is triggered, IKE starts …

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Rationale for IKE

- **shared state must be maintained between source and sink**
  - Which security services (AH, ESP)
  - Which Crypto algorithms
  - Which crypto keys
- **Manual maintenance not scalable**
  - Partially OK only for small scale VPNs
  - In any case, weak approach
    - Infinite lifetime SA → no rekeying!
- **IKE = Internet Key Exchange protocol**
  - Goal: dynamically establish and maintain SA
  - IKE now (december 2005, RFC 4306) in version 2
    - Replaces protocols specified in RFCs 2407, 2408, 2409 (IKE, ISAKMP, DOI)
    - IKEv2 quite different (and much cleaner!!) than former specifications

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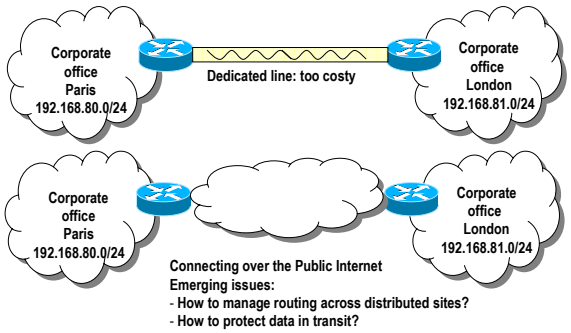
Trying IPsec:
StrongSwan virtual laboratories

http://www.strongswan.org/uml/

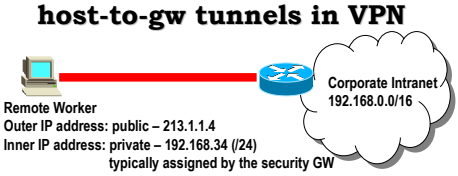
VPN
Virtual Private Network

Virtual Private Networks: why?



Connecting over the Public Internet
Emerging issues:
- How to manage routing across distributed sites?
- How to protect data in transit?

Virtual Private Networks: why? host-to-gw tunnels in VPN



Remote Worker
Outer IP address: public – 213.1.1.4
Inner IP address: private – 192.168.34 (/24)
typically assigned by the security GW

➔**Using a private IP address inside the tunnel:**

⇨Allows to access to all services provided in the intranet, exactly like in the case the worker is connected inside the corporate

Virtual + Private Networks

➔**VPN =**

⇨Virtual Networks (tunnels)

+

⇨Private Networks (authentication, encryption)

➔ **IPsec: a POSSIBLE tool for building VPN**

⇨But IPsec and VPNs are NOT synonymous

➔VPNs can use other technologies:

» e.g. when non-IP traffic must be transported

➔IPsec has other uses:

» e.g. e2e encrypted/authenticated transport

➔**VPN alternatives:**

➔Layer 2: GRE/PPTP, L2TP

➔Layer 3 (actually 3-): MPLS

➔Layer 4 (actually between 4 and 7): SSL tunnels

➔Layer 7: SSH tunnels