PA197 Secure Network Design
4. Security Architectures II

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Content

End2end principle

- Network transparency
  - legacy from the telco network
  - basic two-point communication
- Application architecture $\longrightarrow$ end2end principle
  - the properties of the communication defined at its end points
  - network properties not accounted for
- Security implications
  - communication through channels
  - adding security to these channels
    - encryption at different layers
  - privacy threat: trail between source and destination within network

Secure channels

- Encryption of the communication between concrete layers of the network protocol
  - Explicit encryption by the application before pushing data to the transport stack
  - Secure transport layer: SSL/TLS
  - Secure internet layer: IPsec
- The last two transparent to the application
- Concept of Virtual Private Network (VPN)
  - applications sits on top of secure communication channels
  - mobility of one end-point
  - potential for multi-point communication

IPv4

- IPv4 was not build with the security in mind
  - conceived in times of pure academic (i.e. restricted) use
  - small number of nodes and small number of users
- All information exposed to any eavesdropper
  - destination and source address
  - type of the message (meta-info)
  - content of the message
    - unless explicitly encrypted before transmission
- Security through organizational and legal barriers
  - physical access to the network and attached computers
  - legal restrictions on eavesdropping old telecommunication lines

IPv6

- The security drawbacks of IPv4 recognized
- Full security incorporated as a mandatory requirement
- Integrity
  - not possible to modify the control data
    - source and destination addresses
    - type of the messages
- Content hidden from eavesdropper
  - content encryption
  - possibility to also encrypt most of the metadata
    - e.g. type of message

  However, source and destination address always visible
- The principles transformed into separate protocol description: IPsec
- The mandatory security for IPv6 was dropped in RFC 6434

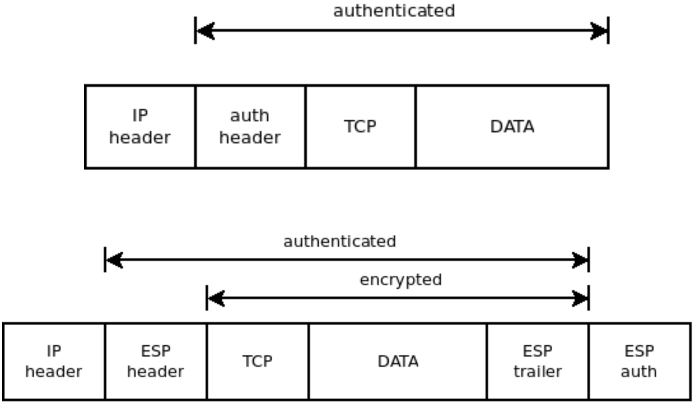
IPsec

- IP security protocol suite
  - first developed for IPv6
  - backpropagated to IPv4 as IPsec
- Addresses security problems of the IP layer
  - Eavesdropping, hijacking, spoofing, ...
- Implemented at the IP layer
- Provides specific protocols/mechanisms
  - confidentiality (no eavesdropping)
  - data origin authentication (no spoofing)
  - message integrity (no data modification)
  - access control
  - replay detection

IPsec Architecture

- Authentication header (AH)
  - data integrity
  - source authentication
- Encapsulating security protocol (ESP)
  - confidentiality (authentication just optional)
- Security association (SA)
  - one directional relationship between sender and receiver
  - establishment of security parameters
  - security association database (SADB)
  - security parameter index (SPI)
    - a unique index for each entry in the SADB
    - associates SA with a packet
  - security policy database (SPD)—"IP sec firewall"
- Transport mode
  - protection of higher-level protocols
- Tunnel mode

IPsec Diagrams



IPsec—Transport Mode

- End-to-end transmission
  - internal active elements not necessarily involved
- Original packet not encapsulated
  - IPsec specific header inserted between original IP and TCP/UDP headers

IPsec—Tunnel Mode

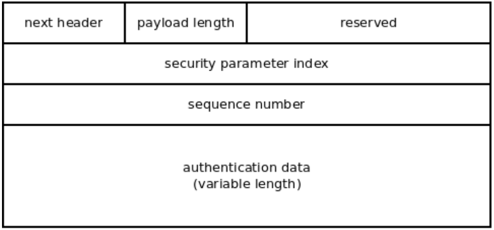
- Tunneling between active elements
  - needs support inside the network
  - at least edge routers must be involved
- Encapsulates original packet
  - prepends new IP header
    - identifies the source and destination addresses of the tunnel
  - IPsec header immediately follows the new (tunnel) IP header
    - the original packet is thus fully encapsulated
    - can be fully encrypted, including the original source/destination addresses

IPsec—Definitions

- A collection of protocols
  - basic: RFC 2401
- Authentication Header (AH)
  - RFC 2402
- Encapsulating Security Payload (ESP)
  - RFC 2406
- Internet Key Exchange (IKE)
  - RFC 2409
- IP Payload Compression (IPcomp)
  - RFC 3137

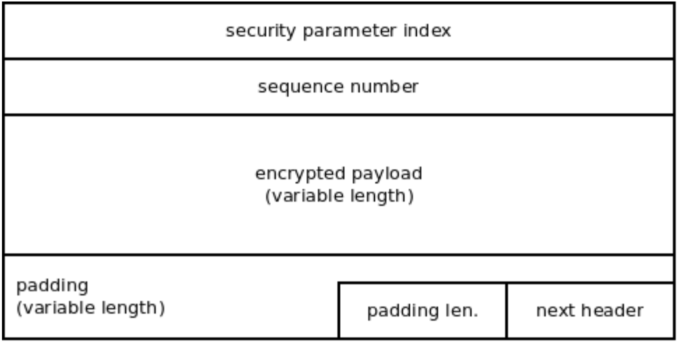
AH Details

- Protection against replay attacks
  - 32-bit monotonically increasing sequence numbers
- Protecting data integrity
  - cryptographically strong hash algorithms (96 bits)
    - symmetric key cryptography
    - HMAC-SHA-96, HMAC-MD5-96



ESP Details

- On top of AH provides data confidentiality
  - symmetric key encryption to encrypt full packets



Internet Key Exchange

- Essential part of IPsec
  - however usable also outside IPsec
- Exchange and negotiate security policies
- Establish Security Associations
- Key exchange
- Key management

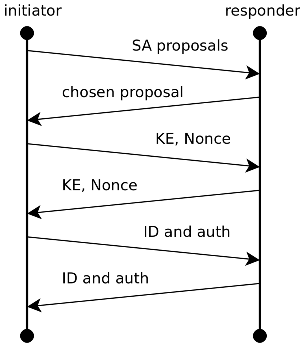
IKE Phases

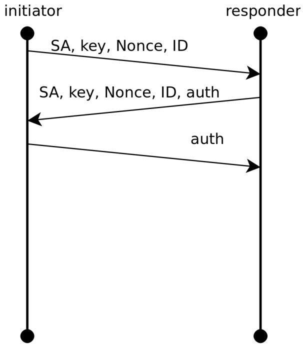
- Phase 1: negotiate and establish an auxiliary e2e secure channel
  - medium for subsequent phase 2
  - only once between any two endpoints
- Phase 2: negotiate and establish custom secure channels
  - for each separate flow
  - occurs many times
- Both phases use Diffie-Hellman key exchange to establish a shared key

IKE Phase 1

- Secure channel between two end-points
- Security features
  - source authentication
  - data integrity and confidentiality
  - protection against replay attacks
- Purpose
  - to provide basic security environment
  - to support secure negotiations for the applications
    - different policies
    - different keys
- Two modes:
  - main mode
    - six messages in three round trips, more options
    - protects the identity of the peers
  - aggressive mode
    - three messages in two round trips, less options

Main vs Aggressive mode





Phase 1 Authentication

- Different ways
  - digital signature
  - two forms of authentication with public key
  - pre-shared key
- Uses public-key based cryptography for encryption

IKE Phase 2

- Custom secure channels
  - using the secure channel established in Phase 1 for setup
  - support heterogeneity
- End-point identification:
  - $<$ IP, Port $>$ (as in transport layer)
  - packet end address (network/range)
    - e.g. all packets for 147.251.11.0/24
- Only quick mode
  - multiplexes multiple quick mode exchanges
  - generates SAs for both end-points

Virtual Private Networks (VPN)

- A network that uses public infrastructure (e.g. Internet) to connect remote offices or users with secure access to their organization's internal network
  - it extends the internal organization's network to remote users in a secure way
- Through the VPN, users are able to use internal applications as if they are within the organization boundaries
- "Classical" VPNs work at Layer 3
  - point to point connection
  - no (limited) support to broadcast domains
- VPNs at Layer 2
  - layer 2 tunneling protocols
  - VPLS
  - extend organizational network also at broadcast domains

Security

- VPNs are (usually) not anonymous
  - some kind of authentication is mandatory
- VPNs are (usually) encrypted
  - protection against eavesdropper over public network
  - confidentiality is provided
- Message integrity is also provided

Basic protocols

- IPsec tunnels
  - standards-based security protocol
- TLS/SSL tunnels
  - used in OpenVPN project
  - can tunnel entire network or just a single user connection
  - alternative to IPsec in NATed and firewalled environment
- Secure Socket Tunneling Protocol (SSTP)
  - Microsoft
  - using SSL3 3.0 to tunnel Point-to-Point Protocol (PPP) or L2 Tunneling Protocol
    - Poodle attack sensitive
- Secure Shell (ssh) VPN
  - OpenSSH
  - VPN tunneling
    - do not confuse with port forwarding

Layer 2 VPN

- Virtual LAN
  - IEEE 802.1Q trunking protocol
  - packet tagging
  - single trunk/single LAN
- Virtual private LAN service (VPLS)
  - multiple tagged LANs share a common trunk
  - it is a provider provisioned VPN, not a private line
  - available for connecting two or more LANs over a public network at L2
  - all connected LANs behave as a single LAN from users' point of view
  - works with frames, not packets
- Ethernet over IP
  - EtherIP (RFC 3378)
  - only packet encapsulation
  - no confidentiality nor message integrity

Layer 3 VPN

- Provider-provisioned services discussed here
  - multiple customers
  - private IP address space disambiguation at the edge device
- BGP/MPLS
  - defined in RFC 2547
  - BGP extensions advertise IPv4 VPN address' routes
    - Route Distinguisher (8 bytes)
    - IPv4 address
  - providers edge routers "know" VPNs' topology
  - MPLS used to tunnel between these edge routers
- Virtual router
  - customer is responsible for the VPN's address space
  - no extensions to the routing
  - MPLS tunnels, different VPNs disambiguated by their label

Mobile VPN

- VPN for mobile devices (mVPN)
  - power (battery) sensitive
  - allows gaps in connections
- Roaming support
  - no single IP address assigned by the network to the mobile end-point
- Uses permanent IP address of the device
  - tunneling VPN
  - software layers take care of tunnels re-connection
  - the end-point IP visible to organization's network does not change

Transport Layer Security

- An attempt to guarantee a transport protocol to prevent eavesdropping and tampering
- A statefull connection
  - a handshake to establish connection security

  that leads to a secure (encrypted) communication channel
- Needs a reliable end-to-end communication channel (TCP)
- Predecessor is the Secure Socket Layer (SSL)
  - the last version 3 (1996, see RFC 6101)
  - insecure, vulnerable to the POODLE attack
- Evolution through Transport Layer Security (TLS) protocol
  - similar but not compatible with SSL
  - version 1.2 (RFC 5246 in 2008)
    - refined in 2011 (RFC 6167)
    - removed backward compatibility with SSL
  - version 1.3 in draft (October 2014)

TLS protocol

- TLS session
  - association between peers (client/server)
  - established by the TLS handshake
  - specifies cryptographic parameters
    - to work over expensive public-key cryptography
    - shared across several connections
- TLS connection
  - mechanisms to transport data
    - type of service
    - how data are sent/received
  - every connection is associated with one TLS session

Basic TLS Handshake

- Always one-way
  - server and client must authenticate independently
- Negotiation phase (server is authenticated)
  - client sends ClientHello message
    - highest TLS protocol it supports; random number; suggested cipher suites; suggested compression methods (not v1.3)
  - server responds with ServerHello handshake
    - chosen protocol version; random number; selected cipher suite and
    - includes also session ID compression method
  - client sends its Certificate
  - server sends its ServerKeyExchange and ServerHelloDone
  - client responds with ClientKeyExchange
    - could include PreMasterSecret key, encrypted with server public key
  - client and server now compute master secret (from PreMasterKey and random numbers)

TLS Handshake II

- Cipher confirmation
  - client sends ChangeCipherSpec record
    - client sends Finished messages containing hash and MAC over previous conversation
    - server checks Finished message and tears down the connection if check fails
  - server does the same towards client (with its own ChangeCipherSpec)
- Application phase
  - handshake is complete
  - all messages are authenticated and encrypted as the Finished message
- Optionally no encryption can be negotiated during the handshake
  - in such case no PreMasterSecret is exchanged and messages are not encrypted

Client-authenticated TLS handshake

- Adding client authentication to the negotiation phase
- Modifications
  - after ServerKeyExchange, server sends CertificateRequest to ask for client authentication
  - after ServerHelloDone, client responds with Certificate message with its own certificate
  - after ClientKeyExchange, clients sends CertificateVerify
    - signature over previous handshake messages
    - signed by client private key
  - server verifies the signature

Resumed TLS handshake

- Uses session ID sent by server during the original full handshake
  - client keeps a triple <session ID; server IP address; TCP port>
  - server keeps the session ID together with the cryptographic parameters negotiated (the master secret)
- Negotiation phase
  - client sends the ClientHello
    - it includes also the session ID from the previous handshake
  - server responds with ServerHello
    - send the same session ID if it recognizes it
    - a different session ID means new full handshake is requested
- Cipher confirmation
  - same as for the full handshake, using the previously stored master secret
- Much shorter, does not need public key cryptography (if the negotiated cipher suite does not need it)

802.1X Protocol

- IEEE standard for Port based Network Access Control
  - part of IEEE 802.1 group of standards
  - authentication framework
  - the actual algorithm how to do it

802.1X—Authentication framework

- Based on Extensible Authentication Protocol (EAP)
  - original RFC 2284 made obsolete by RFC 3748 updated in RFC 5247
- EAP encapsulation over LAN (EAPOL) protocol
  - Ethernet, including 802.11 wireless
  - token rings, including FDDI
- A supplicant request access to an access point (authenticator)
- AP allows only EAP message to be sent by supplicant
- Authenticator sends "EAP-Request/Identity"
- Client returns "EAP-Response/Identity" that is forwarded to the authentication server
  - it either accepts or rejects the authentication request
  - the decision is sent back to access point

  it could (but is not required to) use the Remote Authentication Dial-In User Service (RADIUS)

LEAP and PEAP

- LEAP: Lightweight Extensible Authentication Protocol
  - CISCO-developed 802.1x derivative
  - targets CISCO Aironet equipment
- Uses TKIP and dynamic WEP keys
  - frequent WEP key alteration reduces risks in using this protocol
- PEAP: Protected EAP
  - developed by RSA, Microsoft, and CISCO
  - more advanced than LEAP
- Uses server-side PKI to create an encrypted EAP-TLS tunnels
- This tunnel is used to transmit user's credentials

PANA

- Protocol for Carrying Authentication for Network Access
  - IETF-backed
  - RFC 5191
- IP-based protocol
  - device authentication (to get access)
  - uses EAP
  - PANA carries EAP payload
    - no need for EAPOL or the likes

PANA—Elements

- PANA Client (PaC)
- PANA Authentication Agent (PAA)
  - message exchange with PaC for authentication and authorization
- Authentication Server (AS)
  - stores the info needed to check PaC credentials
  - affirmative reply could contain also some data what is allowed
    - bandwidth parameters
    - IP configuration etc.
    - always time constrained (session time)
- Enforcement Point (EP)
  - filters data from PaC according to the policy
  - a key is established between PaC and EP
  - valid during the session time only

Basic authorization principles

- Least privilege
  - default is no access
  - all privileges must be explicitly defined/assigned
- Separation of duties/privileges
  - no combination of responsibilities in one person/entity
- Need to know
  - access only to the information (infrastructure) needed to perform the work
- Complete mediation
  - All accesses must be checked

Access Control

- The criteria used to decide on access usually include one or more from the following:
  - roles
  - groups
  - location
  - time
  - type of access

Trusted Network Connect (TNC)

- An activity to define an open solution architecture for access control to the network endpoints
  - TNC-Working Group: companies, government, academia
  - first introduced in 2005
- TNC reference architecture
  - federated TNC protocol (IF-FTNC) which enables communication of
  - IF-M attributes
  - IF TNCCS Access recommendations
  - IF-MAP metadata from one security domain to another
- To support network administrators in protecting networks
  - impose enterprise security policies
  - audit endpoint configurations

TNC Key Elements

- Network Access Requester (NAR)
  - a client software on endpoint that initiates the network access attempt
    - VPN client, 802.1x supplicants, web browser with initiating TLS handshake etc.
- Policy Enforcement Point (PEP)
  - network infrastructure device
    - 802.1x compliant
  - forwards information about NAR to PDP
- Policy Decision Point (PDP)
  - a device that hosts NEA
- Network Access Authority (NEA)
  - determines the fate of the NAR request

Summary

- Two major concepts
  - secure end-to-end communication
  - access control to the network
- Different ways for secure channels
  - IPsec in details (including IKE)
  - animation of IPsec functionality: `http://frakira.fi.muni.cz/~jeronimo/vyuka/IPSec`
- VPNs
  - for end users and between sites
  - L2 and L3 protocols
- 802.1x protocol for authentication
- Access control
  - Basic authorization principles
  - Trusted Network Connection
- Next session: Advanced architectures