TÉCNICO LISBOA

# IPsec and VPNs

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# Roadmap

- IPsec
  - Main mechanisms
  - Key distribution
- VPNs and tunneling

# Roadmap

- **IPsec**
  - **Main mechanisms**
  - Key distribution
- VPNs and tunneling

# Secure communication: Network layer

| Layers | | Responsibility | Approach | Solutions |
|---|---|---|---|---|
| | Transaction | Local data manipulation applications | End-to-end security | PGP, PEM, S/MIME |
| OSI Layers | Application | Applications for remote data exchange | | HTTPS, IMAPS SSH |
| | Presentation | | | |
| | Session | | | |
| | Transport | Operating Systems | | TLS |
| | Network | | | IPsec |
| | Link | Devices | Link security | IEEE 802.11* |
| | Physical | | | |

# IP security

- Goals
- Operational scenarios
- Gateway
- Establishment of SA (Security Associations)

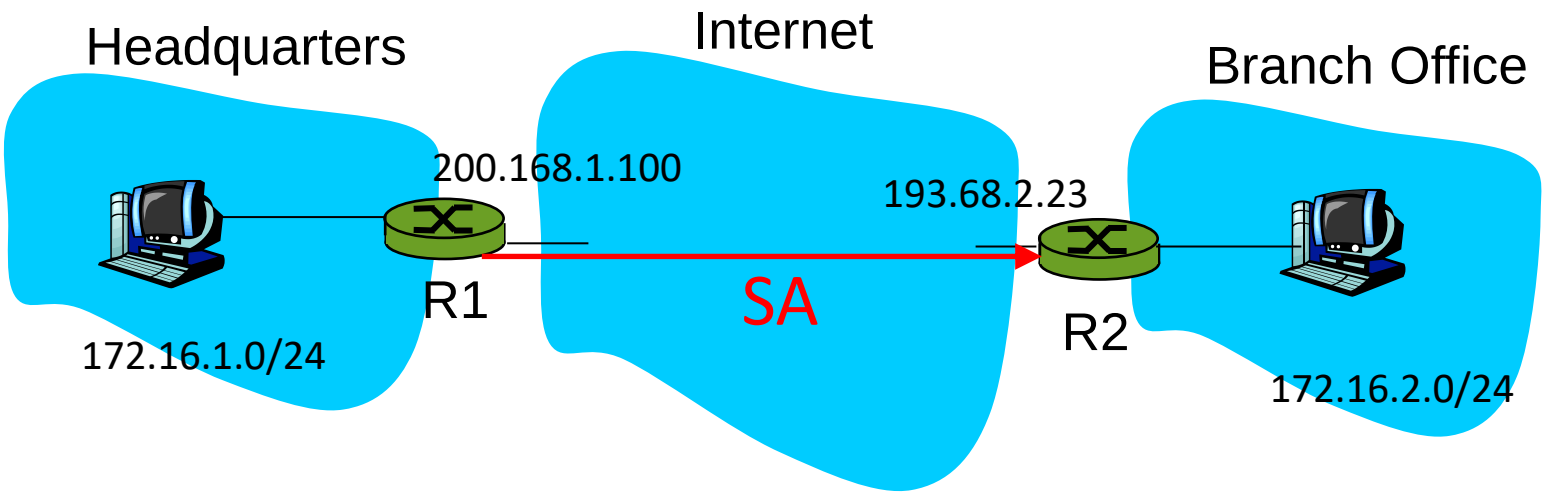
# IPsec goals

- Protect all IP traffic between nodes:
  confidentiality, integrity, freshness, authenticity
- Two modes of operations:
  - **Transport Mode**: the original IP header is used for routing
  - **Tunnel Mode**: the original IP header is encapsulated
- Benefits
  - Provides secure channels
  - Only affects the network layer; transparent to higher-layer protocols
  - Avoids the update/modification of existing distributed applications
  - Uses the existing IP routing infrastructure; IP header is in plaintext
  - Security between endpoints is independent of the ISPs

# SAs (Security Associations)

- Before sending data, **security associations (SAs)** are established at sending and receiving entity
- SAs are **simplex**, i.e., one for each direction
- Gateways maintain *state information* about SAs
  - IP is connectionless; **IPsec is connection-oriented**!

# Example SA from R1 to R2



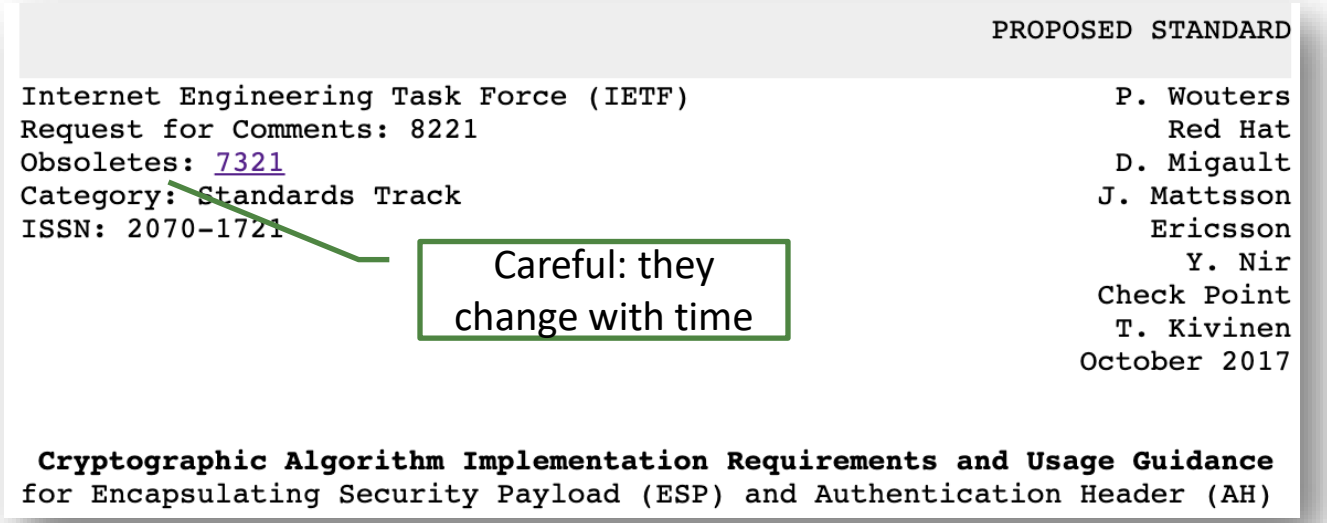

## Router 1 stores for an SA:

- 32-bit SA identifier called **SPI (Security Parameter Index)**
- Origin SA interface IP address (200.168.1.100)
- Destination SA interface IP address (193.68.2.23)
- Type of encryption used (e.g., AES with CBC)
- Encryption key
- Type of integrity check used (e.g., HMAC with SHA-2)
- Authentication key (for obtaining HMACs)

# SAD (Security Association Database)

- Endpoint holds SA state in the **SAD database**, where it can locate them during processing
  - The SAD is indexed using the **SPI (Security Parameter Index)**
- When **sending** IPsec datagram:
  - R1 accesses SAD to determine how to process the datagram
- When IPsec datagram **arrives** to R2:
  - R2 fetches the **SPI** from the IPsec datagram
  - indexes SAD with the **SPI**
  - and processes datagram accordingly

# IPsec cryptographic techniques



PROPOSED STANDARD

Internet Engineering Task Force (IETF)
Request for Comments: 8221
Obsoletes: 7321
Category: Standards Track
ISSN: 2070-1721

Careful: they change with time

P. Wouters
Red Hat
D. Migault
J. Mattsson
Ericsson
Y. Nir
Check Point
T. Kivinen
October 2017

**Cryptographic Algorithm Implementation Requirements and Usage Guidance**
for Encapsulating Security Payload (ESP) and Authentication Header (AH)

- RFC 8221 (Oct 2017) essentially mandates:
  - ESP Encryption Algorithms: AES, ChaCha20
  - ESP and AH Authentication Algorithms: HMAC w/SHA-2
- In fact, it is more complicated:
  - It defines specific configurations of the algorithms
  - It makes “should”, “must”, “must not” statements

# IPsec sub-protocols

- IPsec has two sub-protocols: AH and ESP

- **Authentication Header (AH)**
  - Can provide source authentication, data integrity, freshness, but ***not*** confidentiality
- **Encapsulation Security Protocol (ESP)**
  - Can provide source authentication, data integrity, freshness, ***and*** *confidentiality*

# AH vs ESP

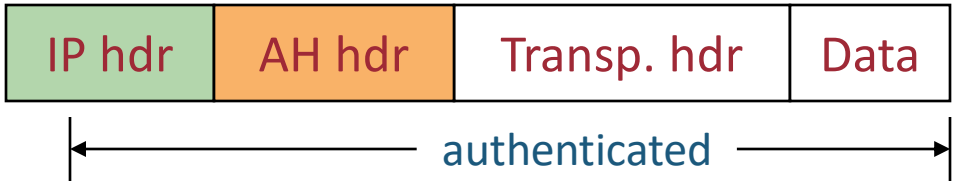
- **Authentication Header**
  - Can prevent IP spoofing (packet tampering) but **not** eavesdropping
  - Simpler and lower overhead than ESP

- **Encapsulation Security Protocol**
  - Can prevent IP spoofing (packet tampering) and eavesdropping
  - ESP provides encryption and optional authentication

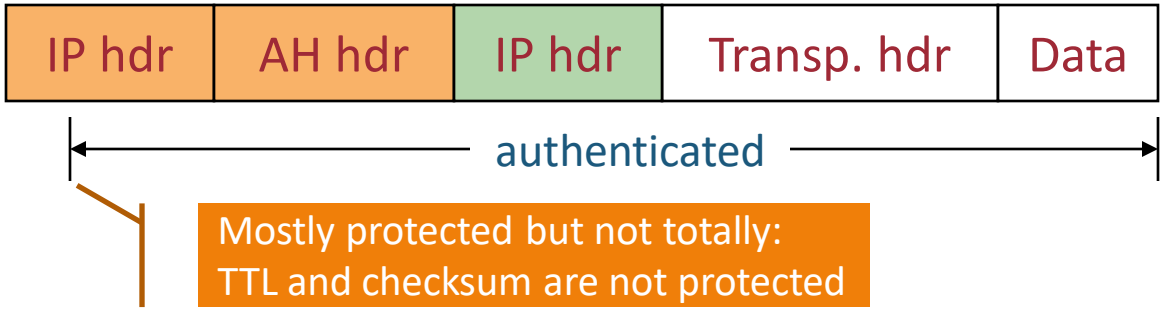
# IPsec AH (Authentication Header)

## Original packet

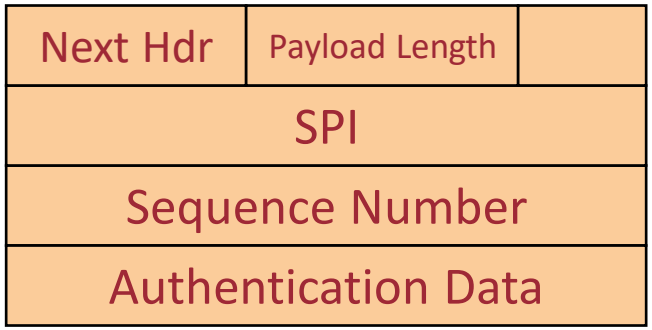

## Transport mode




## Tunnel mode



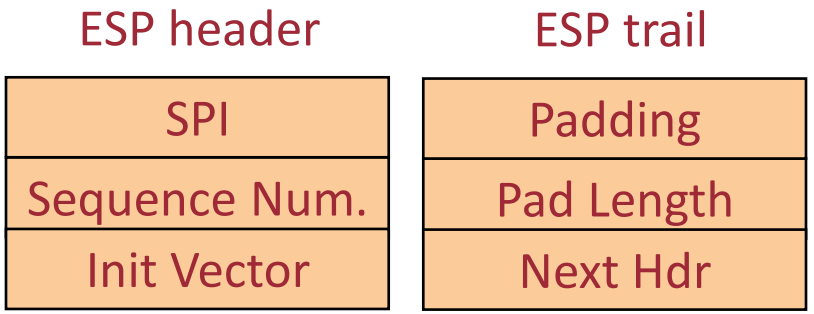

## AH header



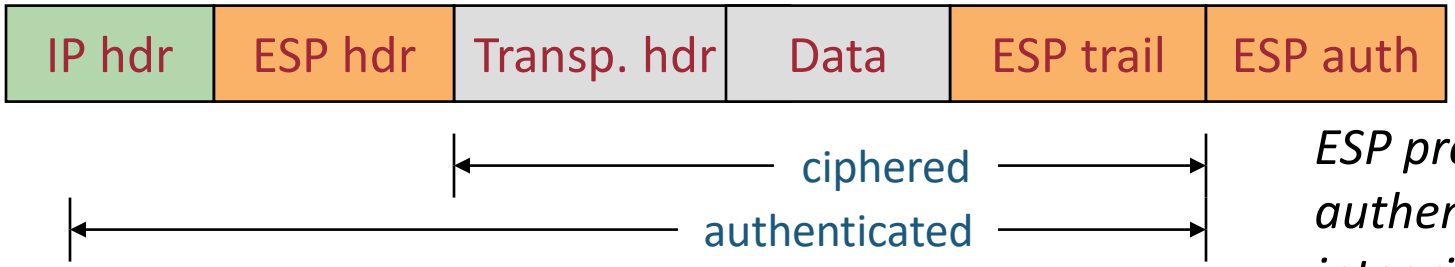

*AH provides source authentication, data integrity, freshness, but not confidentiality*

# IPsec ESP (Encapsulating Security Payload)

Original packet

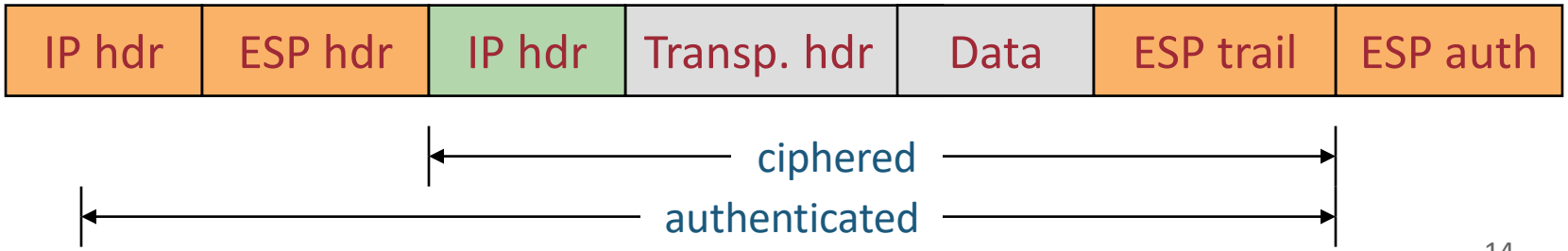




## Transport mode

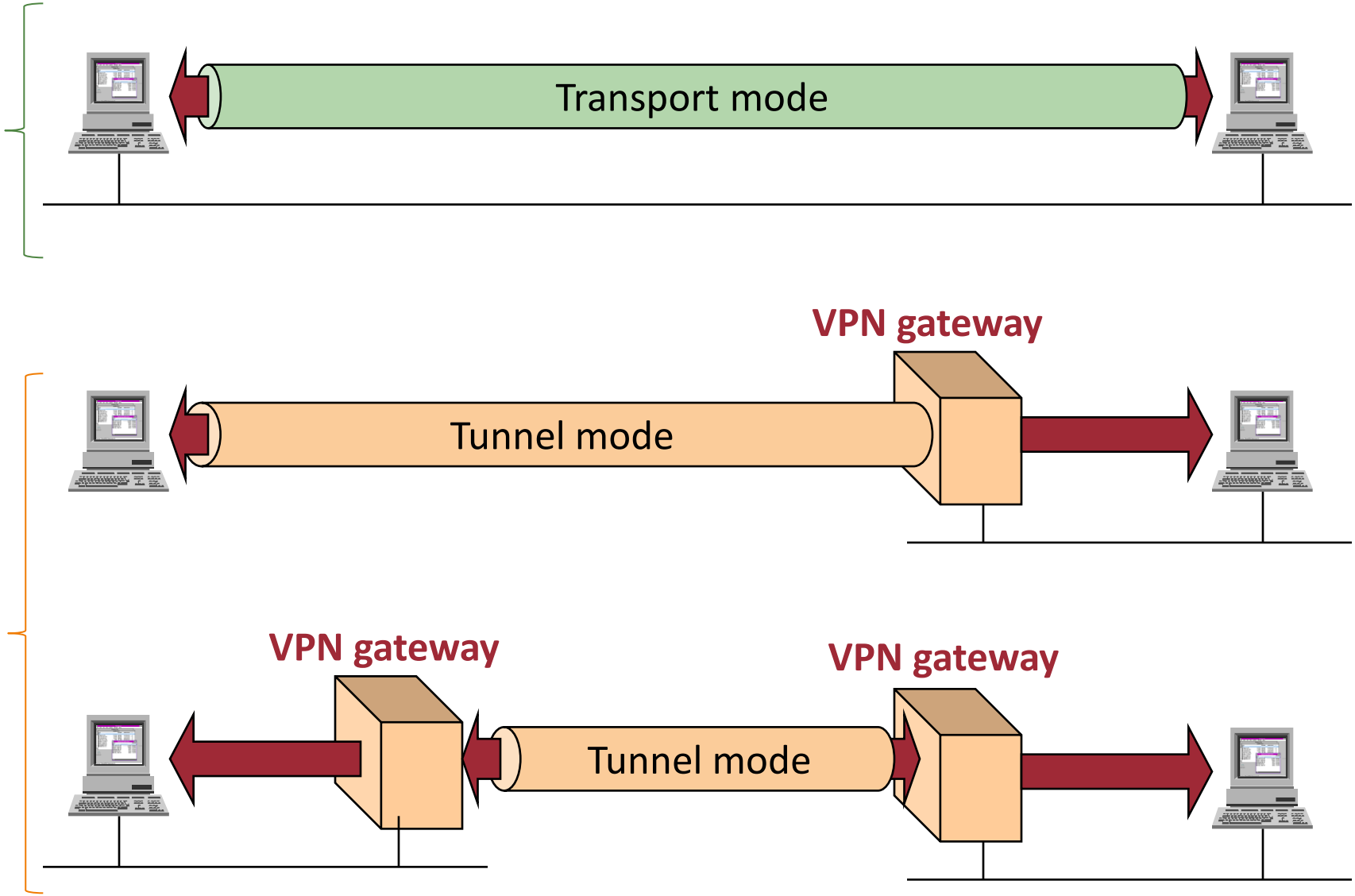



*ESP provides source authentication, data integrity, freshness, and confidentiality*

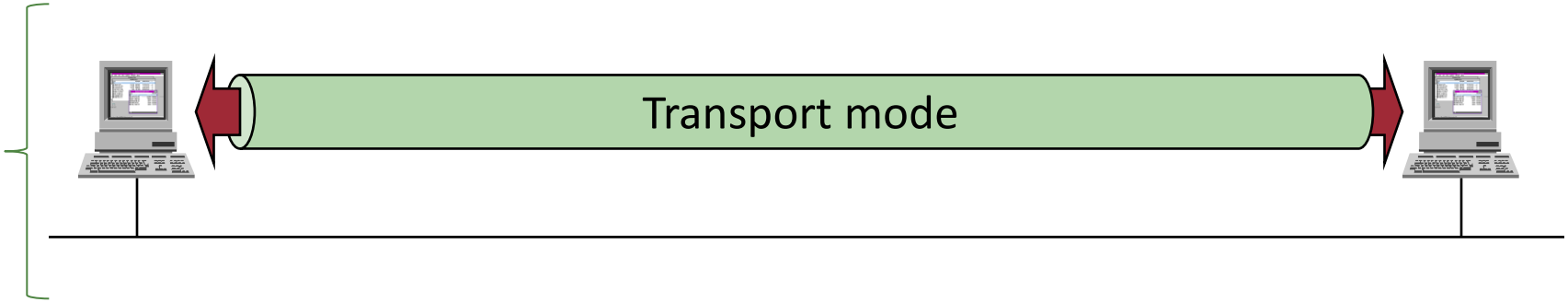
## Tunnel mode



# IPsec operational scenarios



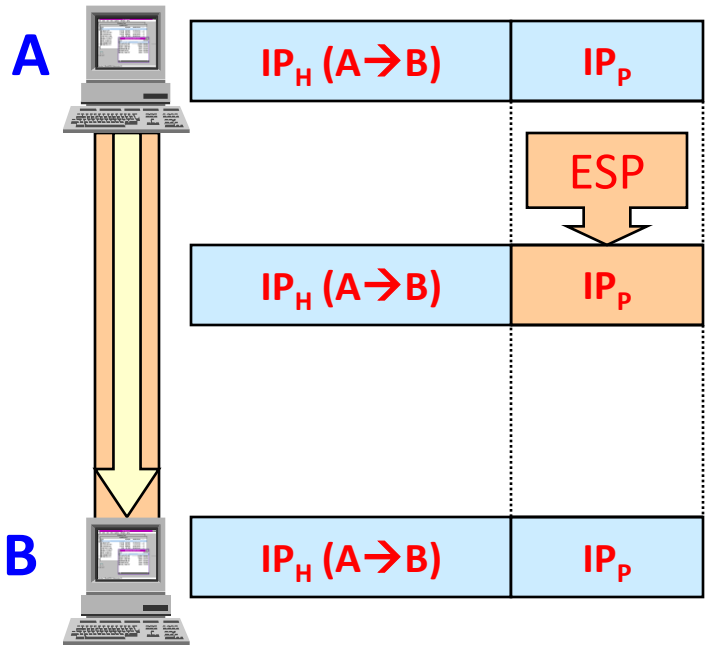
# IPsec operational scenarios: host-to-host



# ESP Transport Mode

- **Transport Mode**: the original IP header is used for routing
- ESP is deciphered by the destination host
  - Deciphers the ESP and reconstructs the original datagram
- ESP auth (MAC) is verified by the destination host
- SA in use is indexed by the SPI of the datagram

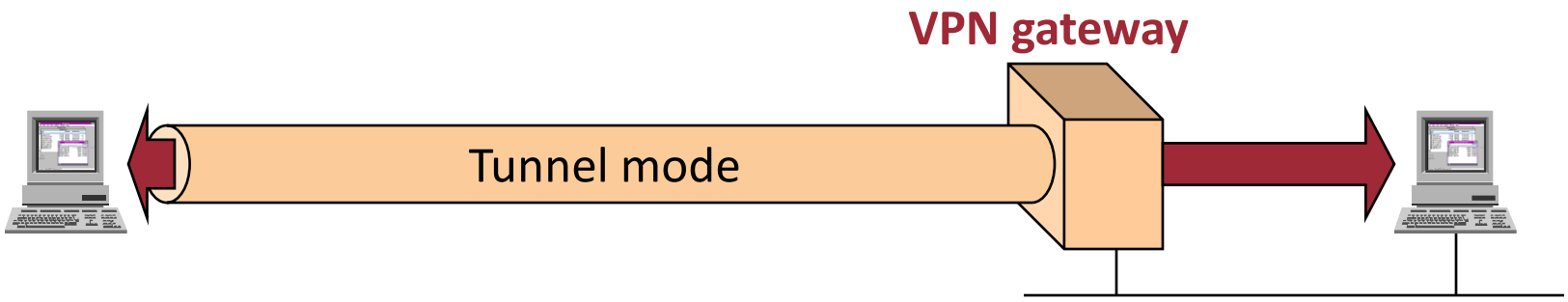
# Host-to-host using ESP Transport Mode




$IP_H$ – IP header
$IP_P$ – IP payload

- **Host-to-host**
  - IPsec security exists between A and B
  - Both machines need to to know how to use IPsec
- Machine A and B take the initiative of using IPsec between them
  - Two SAs must exist between A and B

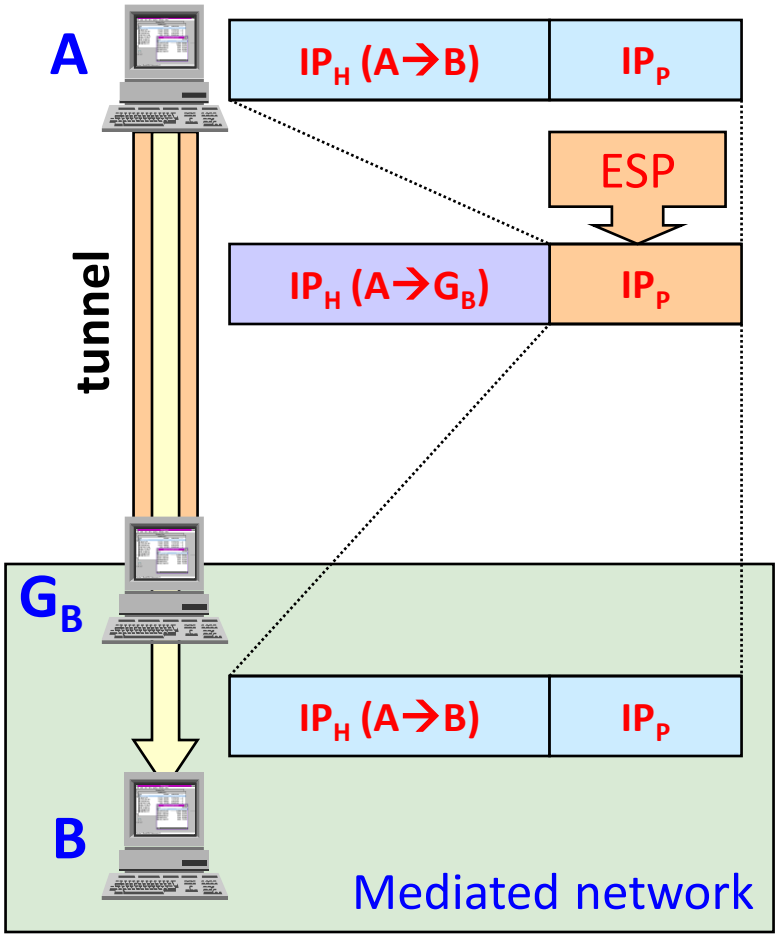
# IPsec operational scenarios: host-to-net



# ESP Tunnel Mode with gateway

- **Encapsulating Security Payload (ESP)** created with a **full IP datagram**
- Operation
  - Sender or gateway generates ESP with datagram addressed to machine B
  - The final datagram is sent to the gateway of B
    - Host IP addresses may be private
  - The ESP is deciphered; integrity is checked by the gateway of B, then sent to B
- Additional advantages
  - Conceals the real IP addresses from the intermediate nodes
- Disadvantages
  - Increases the IP packet size

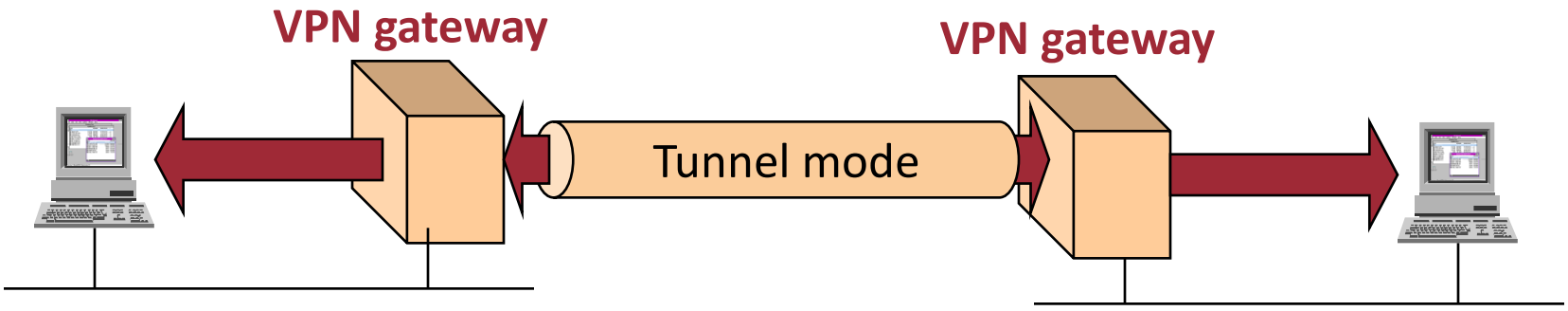
# Host-to-net VPN using ESP Tunnel Mode



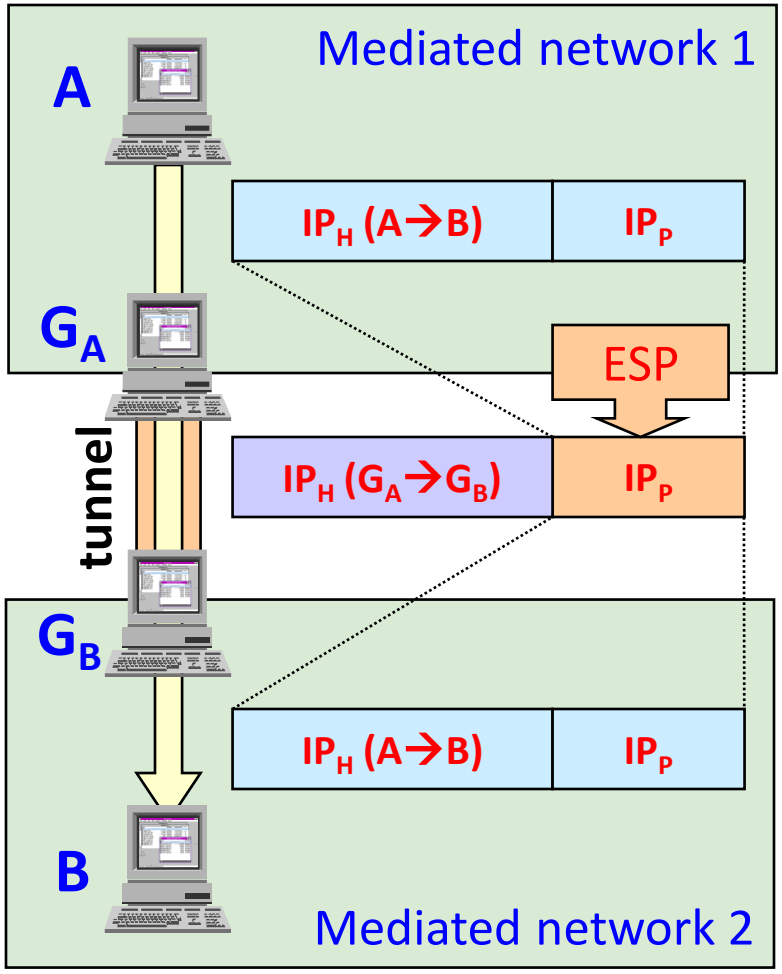

$IP_H$ – IP header
$IP_P$ – IP payload

- **Host-to-net VPN**
  - IPsec security exists between A and gateway $G_B$
  - Machine B does not need to know how to use IPsec
  - The address of B does not have to be public
- Host A and gateway $G_B$ take the initiative of using IPsec tunneling between them
  - Two SAs must exist between A and $G_B$

# IPsec operational scenarios: net-to-net



# Net-to-net VPN using ESP Tunnel Mode




$IP_H$ – IP header
$IP_P$ – IP payload

- **Net-to-net VPN**
  - IPsec security exists between gateways $G_A$ and $G_B$
  - Machines A and B do not need to know how to use IPsec
  - The IP addresses of A and B do not have to be public
- Gateways $G_A$ and $G_B$ take the initiative of using an IPsec tunnel between them
  - Two SAs must exist between them

# IPsec limitations

- Performance
  - All the dataflow between two nodes is protected
    - Even if not needed
  - Tunneling size overhead
    - More headers, more processing
- Security quality
  - Some messages are more critical than others
    - Depending on the applications and the users
  - There may be need of assuring security at higher layers
    - Leading to a duplication of effort
- Key management
  - There is no unique key management protocol
    - The most common solution is manual distribution

# Roadmap

- **IPsec**
  - Main mechanisms
  - **Key distribution**
- VPNs and tunneling

# IPsec SA establishment (1/2)

- **Security Association (SA)**
  - Security policy, cryptographic mechanisms, and parameters used in the secure communication between a pair of machines
  - Security Parameter Index (SPI)
- Problem
  - How to create common SAs between a pair of machines?
  - Which is the SPI of those SAs?

# IPsec SA establishment (2/2)

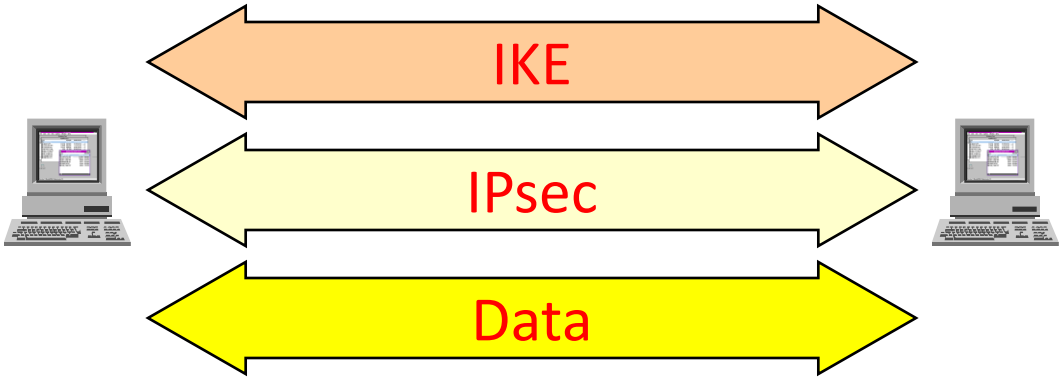
- Manual establishment
  - Manual configuration of the SAs
  - Manual attribution of SAs to IPs
- SA establishment with protocols
  - **ISAKMP** – framework
  - **IKE** – the standard protocol (IKEv2)

# ISAKMP

- **ISAKMP** – Internet Security Association and Key Management Protocol
- Generic protocol (framework)
  - Allows the negotiation of keys and entity authentication
    - Does not specify any techniques
    - Only defines 5 types of information exchange
- It is an application layer protocol
  - Supports negotiations for several OSI layers
- There is only one protocol that uses it:
  - **IKE: Internet Key Exchange,** the standard for IPSEC
  - but can also be used with TLS

# IKE operation

- IKE – Internet Key Exchange
- 1st phase: establishment of a bidirectional **IKE SA**
- 2nd phase: establishment of unidirectional **IPsec SAs**
  - Negotiation protected by the IKE SA
  - Several IPsec SAs can be established using the same IKE SA
- Data transmission secured by IPsec
  - Protected by unidirectional IPsec SAs



# IKE negotiation modes

- Main mode (1st phase)
  - Establishment of a bidirectional IKE SA
  - Instance of the identity exchange of the ISAKMP
  - Ciphered identities (machine names)
    - The IKE SA can be negotiated by a third party rather than the machines using them
- Quick mode (2nd phase)
  - Establishment of two IPsec SAs
    - One for the outgoing data,
    - Another one for the incoming data (with its SPI)
  - Protected by an IKE SA
  - Generates a new key with DH (Diffie-Hellman) or refreshes the previous key

# IKE: host authentication

- 1st Phase: two alternatives:
  - With **asymmetric cryptography**
    - DSA/RSA signatures and X.509 digital certificates
  - With a **shared secret**
    - Pre-shared key (PSK) – secret key, established manually
- 2nd Phase
  - With **shared secret** only
    - Uses secret established in the first phase

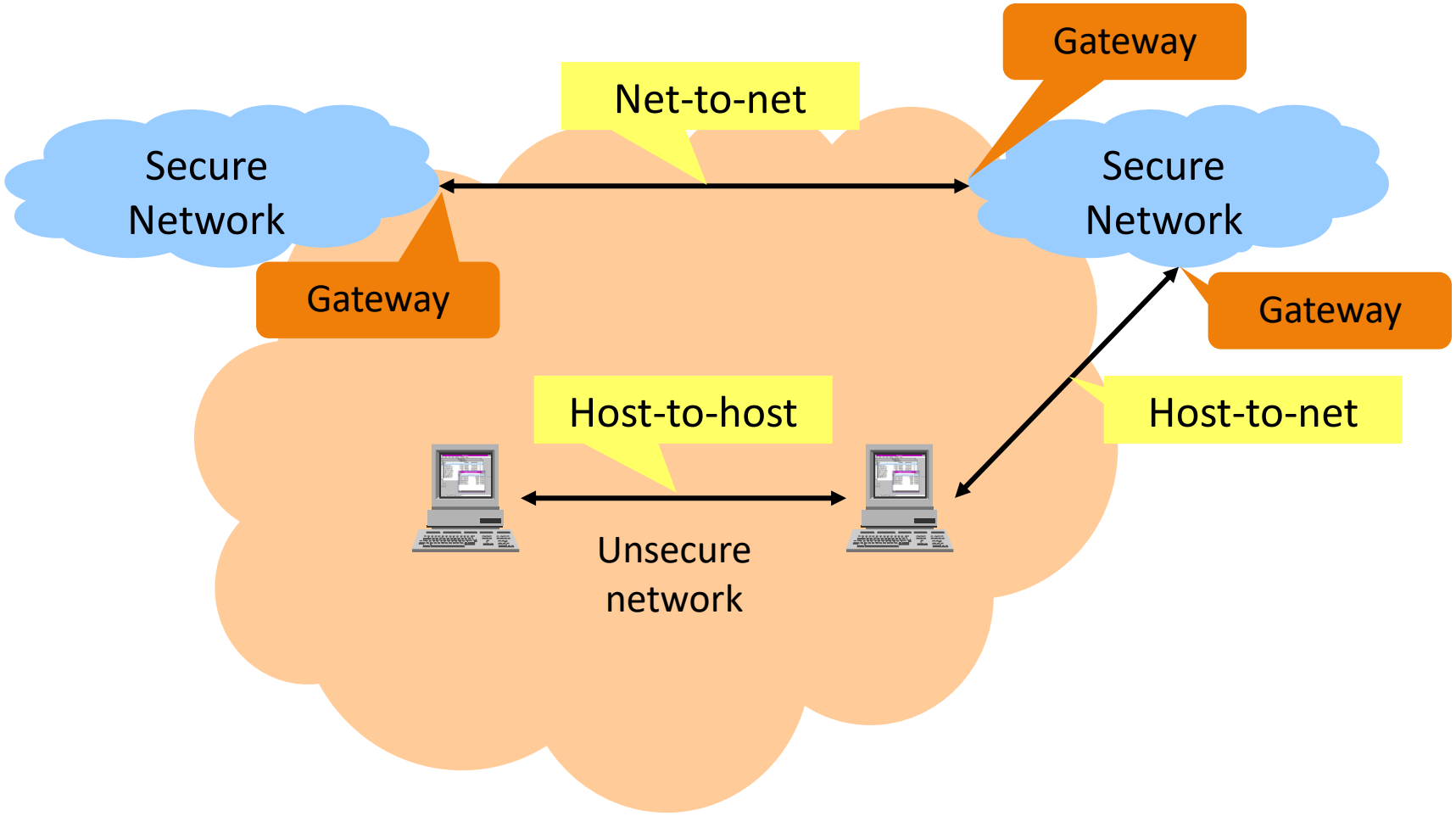
# Roadmap

- IPsec
  - Main mechanisms
  - Key distribution
- **VPNs and tunneling**

# VPN (Virtual Private Network)

- A **VPN** extends a private network across a public network
  - Enables users to send and receive data across shared or public networks
  - **As if** their computing devices were **directly connected** to the private network
- Applications running across a VPN may benefit from the functionality, security, and management of the private network

# VPN usage modes



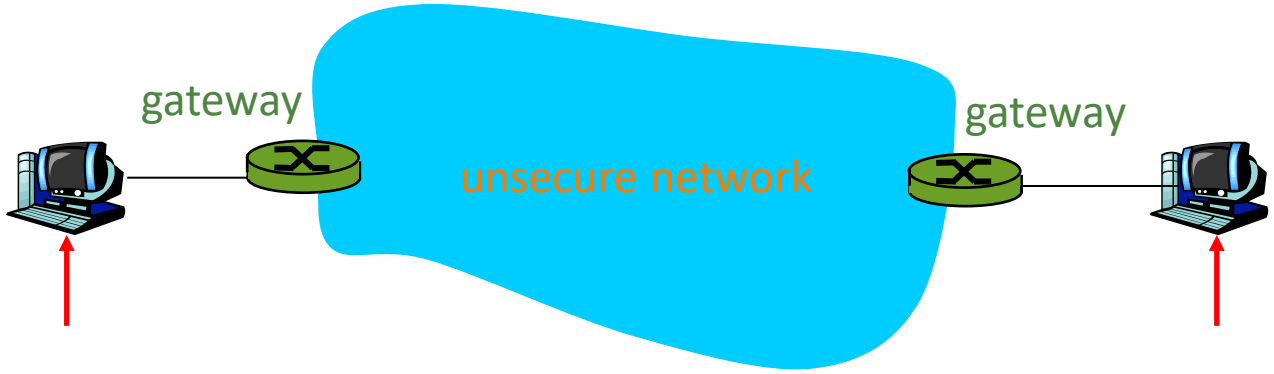
# Tunneling

- Objective
  - Encapsulating a protocol inside another protocol


- Security benefits
  - Allows to associate security to the tunneling operation
  - Without interfering with the management infrastructure of the core protocol

# VPN Gateway

- Communication unprotected in **internal networks**
  - Where it is assumed that no risk exists
- When data flows into an **unsecure network**, a **VPN gateway** transforms it to assure security
- Additional benefits
  - Intermediate nodes, e.g., Internet routers, can be unaware of secure channel
  - Firewall between gateway and node has access to data in cleartext



# Summary

- IPsec
  - Main mechanisms
  - Key distribution
- VPNs and tunneling