Internet Security Protocols

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With thanks to Joris Claessens and Walter Fumy

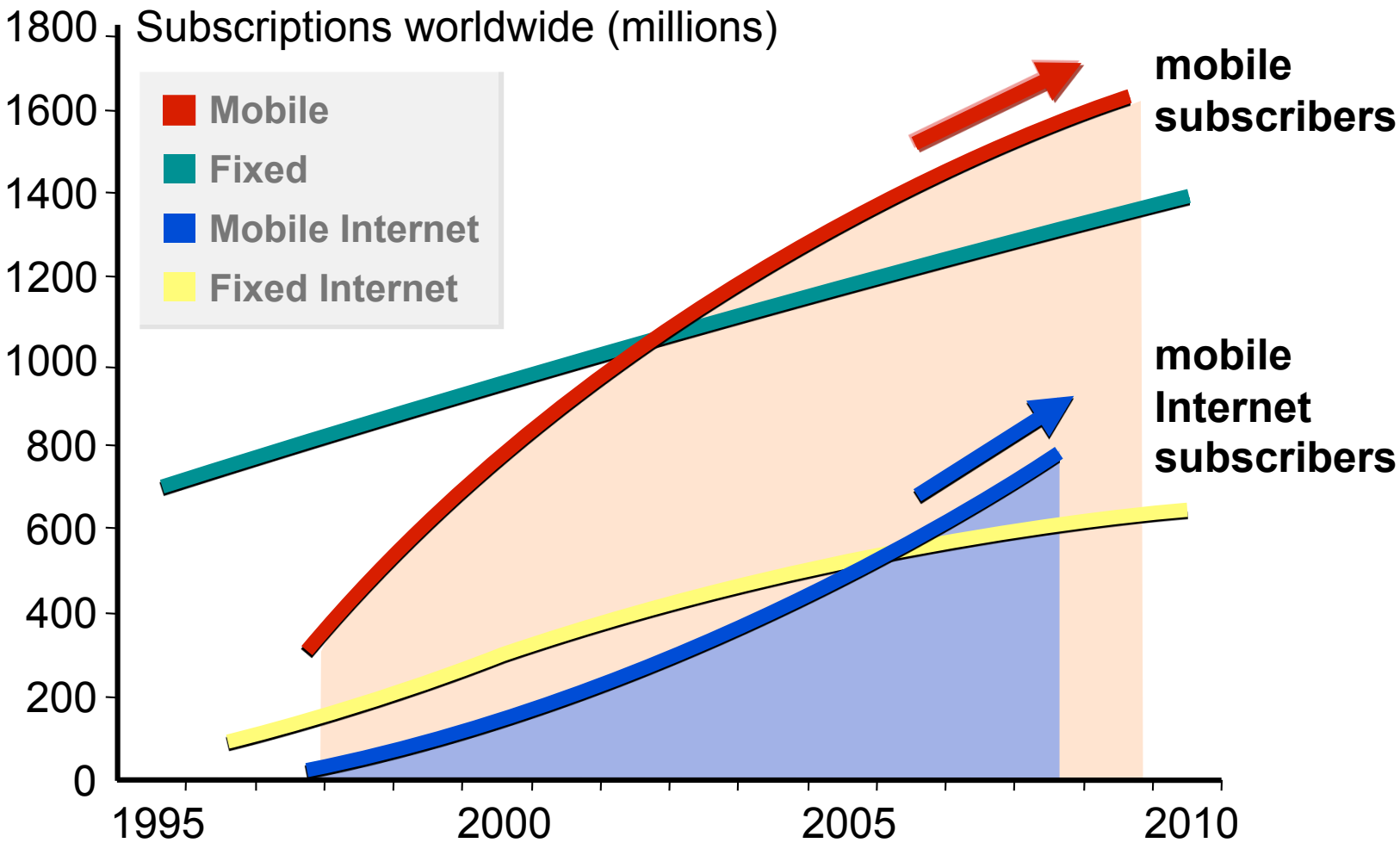
Context

- 1. Cryptology: concepts and algorithms
- 2. Cryptology: protocols
- 3. Public-Key Infrastructure principles
- **4. Networking protocols**
- 5. New developments in cryptology
- 6. Cryptography best practices
- 7. Hash functions

Outline

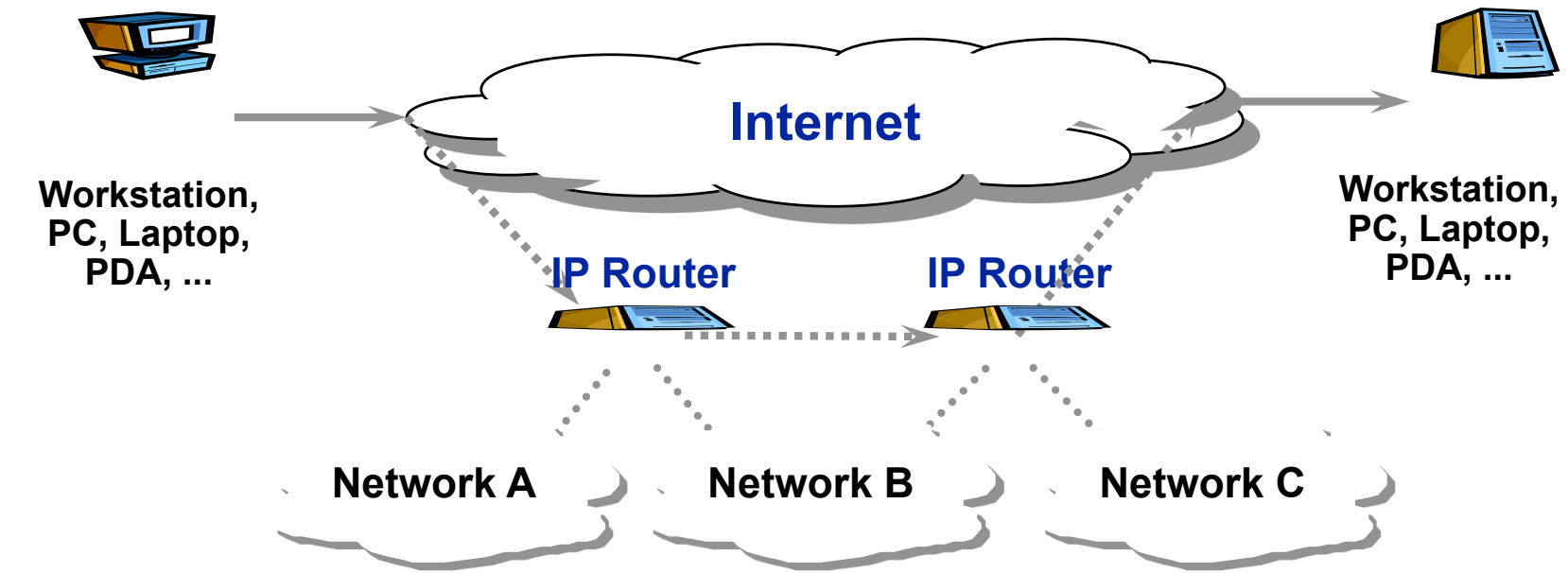
- Internet summary
- IETF process
- Basic principles
- Transport layer security
  - SSL / TLS
- Network layer security
  - IPSec, VPN, SSH

Internet Evolution



The Internet - A Network of Networks

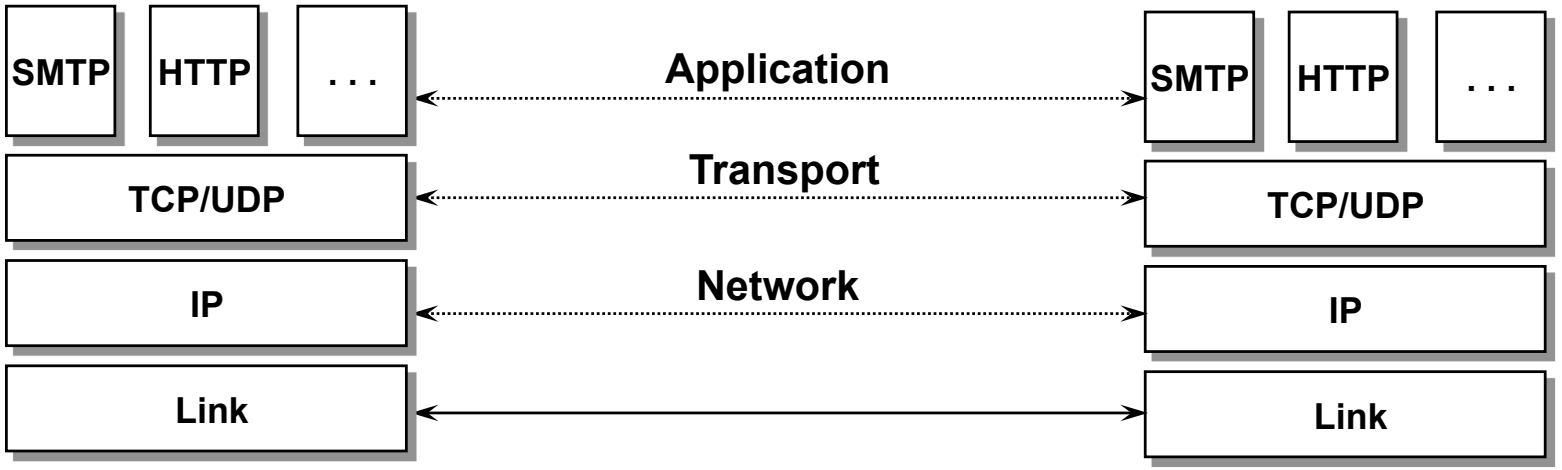
- "IP is the protocol that integrates all infrastructures"



various transmission technologies

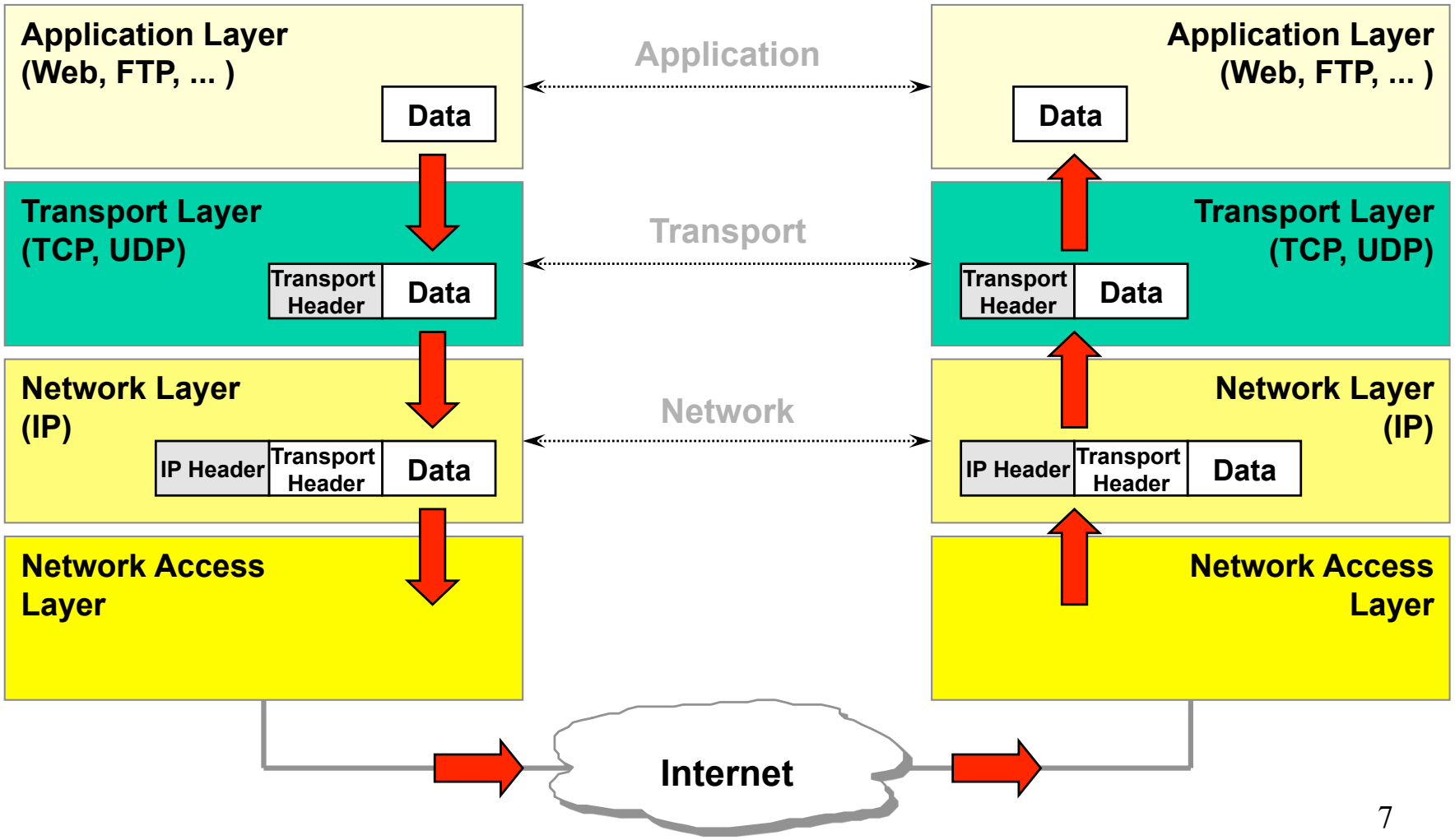
Network A	Network B	Network C
Ethernet	DECT	PSTN
Token Ring	GSM	ISDN
WLAN	UMTS	ATM
Powerline	Satellites	Frame Relay

Internet Protocols



- **Network Layer**
  - Internet Protocol (IP)
- **Transport Layer**
  - Transmission Control Protocol (TCP), User Datagram Protocol (UDP)

Data Encapsulation



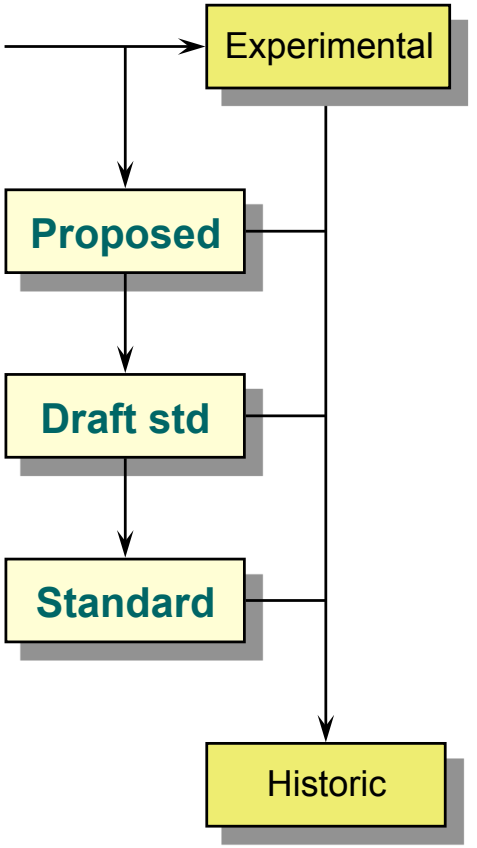
Internet Standardization

Rough Consensus & Running Code

- **ISOC/IAB/IESG/IETF**
- **Internet Engineering Task Force** (IETF)
- IETF Working Groups
  - Mailing List Information
  - Scope of the Working Group
  - Goals and Milestones
  - Current Internet Drafts & RFCs
  - http://www.ietf.org/html.charters/wg-dir.html
- RFCs
  - http://www.rfc-editor.org
  - ftp://FTP.ISI.EDU/in-notes/

IETF Standards: RFC

- **Proposed Standard (PS)**
  - stable spec
  - lowest level of standards track
- **Draft Standard (DS)**
  - at least two independent and interoperable implementations
- **Standard (STD)**
  - widely, successfully used



IETF Intermediate documents

- **Request for Comments (RFCs) with different maturity levels**
  - Experimental (E)
  - Informational (I)
  - Historic (H)
  - Best Current Practice (BCP)
- **Internet-Drafts** (I-D) are working documents of the working groups and have **no formal status**
- **Protocol Status (requirement level)**
  - "required", "recommended", "elective", "limited use", or "not recommended"
  - “must” and “should”

IETF Security Area

Area Directors: Stephen Farrell, Tim Polk, Sean Turner

abfab	Application Bridging for Federated Access Beyond web
dane	DNS-based Authentication of Named Entities
dkim	Domain Keys Identified Mail
emu	EAP Method Update
hokey	Handover Keying
ipsecme	IP Security Maintenance and Extensions
isms	Integrated Security Model for SNMP
kitten	Common Authentication Technology Next Generation
krb-wg	Kerberos
ltans	Long-Term Archive and Notary Services
msec	Multicast Security
nea	Network Endpoint Assessment
pkix	Public-Key Infrastructure (X.509)
tls	Transport Layer Security

Communications insecurity

- architectural errors
  - wrong trust assumptions
  - default = no security
- protocol errors
  - unilateral entity authentication
  - weak entity authentication mechanism
  - downgrade attack
- modes of operation errors
  - no authenticated encryption
  - wrong use of crypto
- cryptographic errors
  - weak crypto
- implementation errors

range of wireless communication is often underestimated!

A historical perspective (1)

wireless data

1900 1960 1980 1990 2000

Vernam: OTP

rotor machines

LFSR

WLAN
PAN
3GSM

wired data

1900 1960 1980 1990 2000

block ciphers

X25

TLS SSH IPsec

digital encryption

wired voice

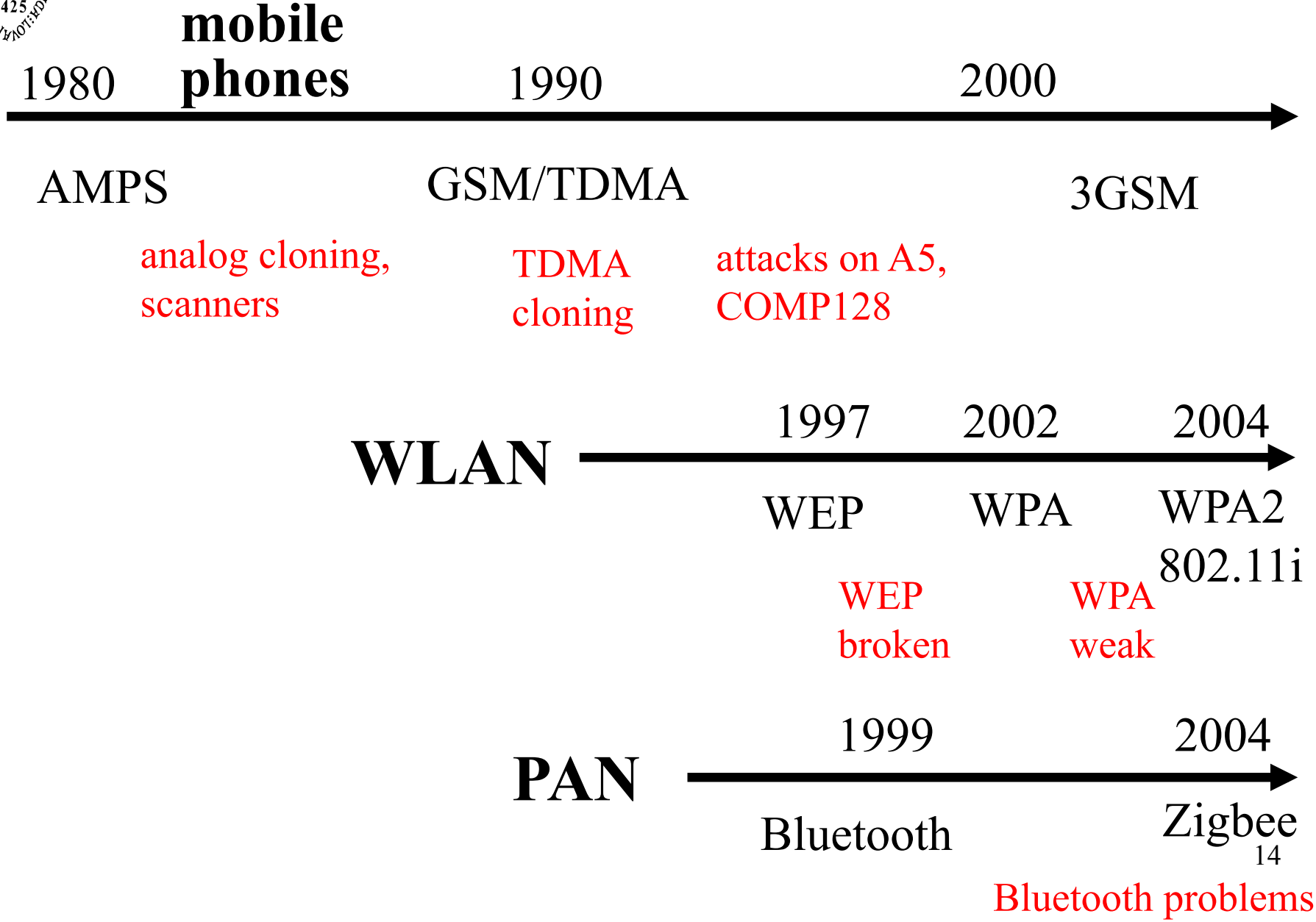
1900 1960 1980 1990 2000

analog scramblers

STU

VoIP

A historical perspective (2)

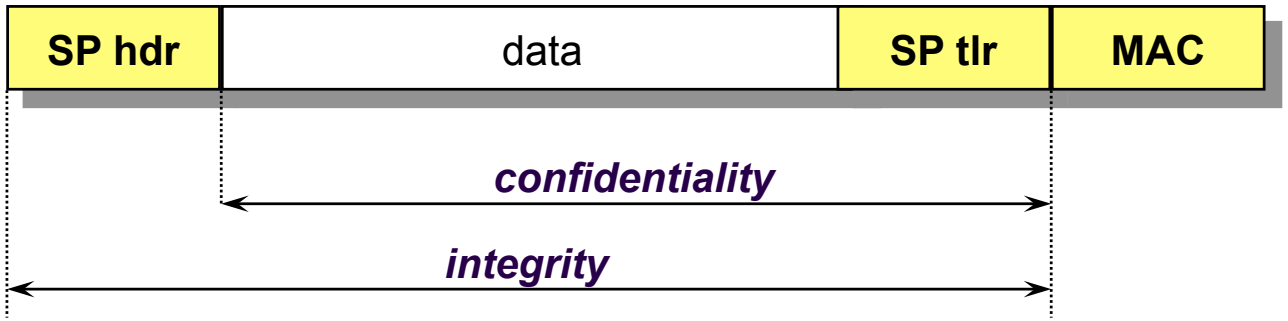


Security Goals (started in ISO 7498-2)

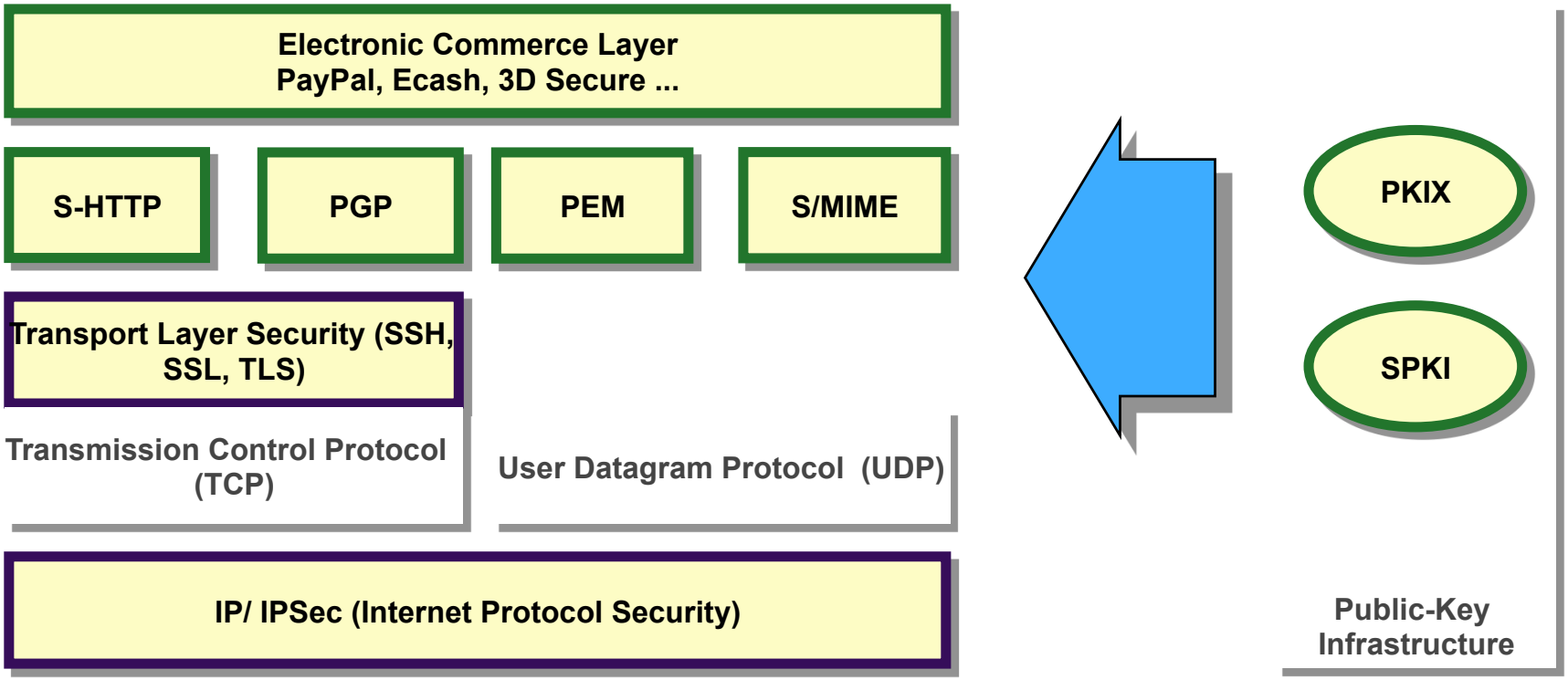
- confidentiality:
  - entities (anonimity)
  - data
  - traffic flow
- (unilateral or mutual) entity authentication
- data authentication (connection-less or connection-oriented): data origin authentication + data integrity
- access control
- non-repudiation of origin versus deniability

Security Protocols & Services

- Cryptographic techniques:
  - symmetric encipherment
  - message authentication mechanisms
  - entity authentication mechanisms
  - key establishment mechanisms (e.g., combined with entity authentication)



Internet Security Protocols

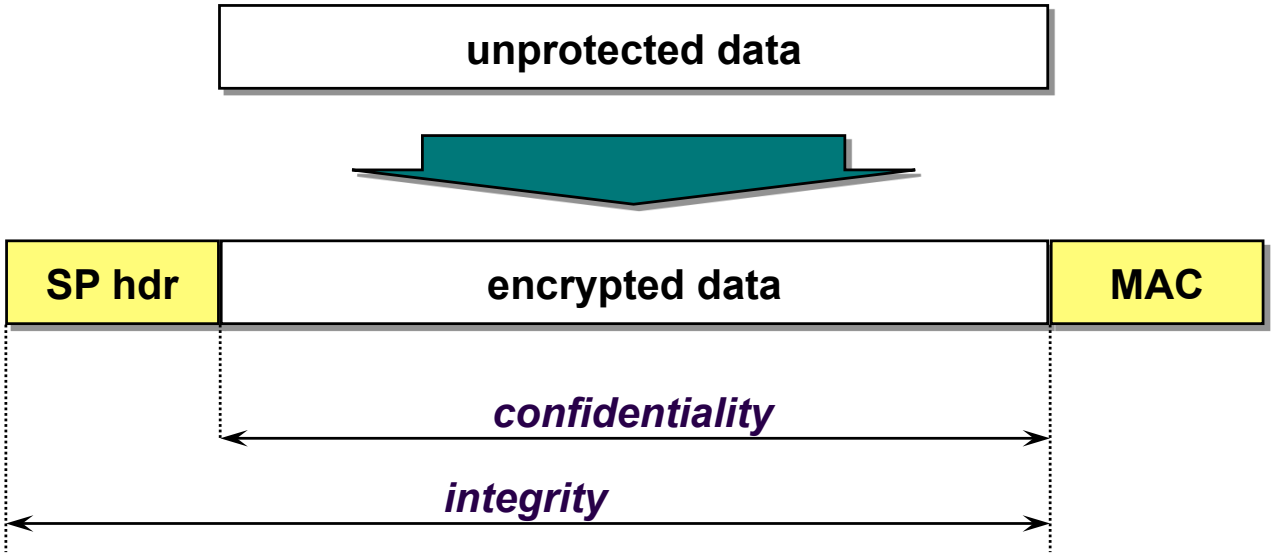


- security services depend on the layer of integration:
  - the mechanisms can only protect the payload and/or header information available at this layer
  - header information of lower layers is not protected!!

Security: at which layer?

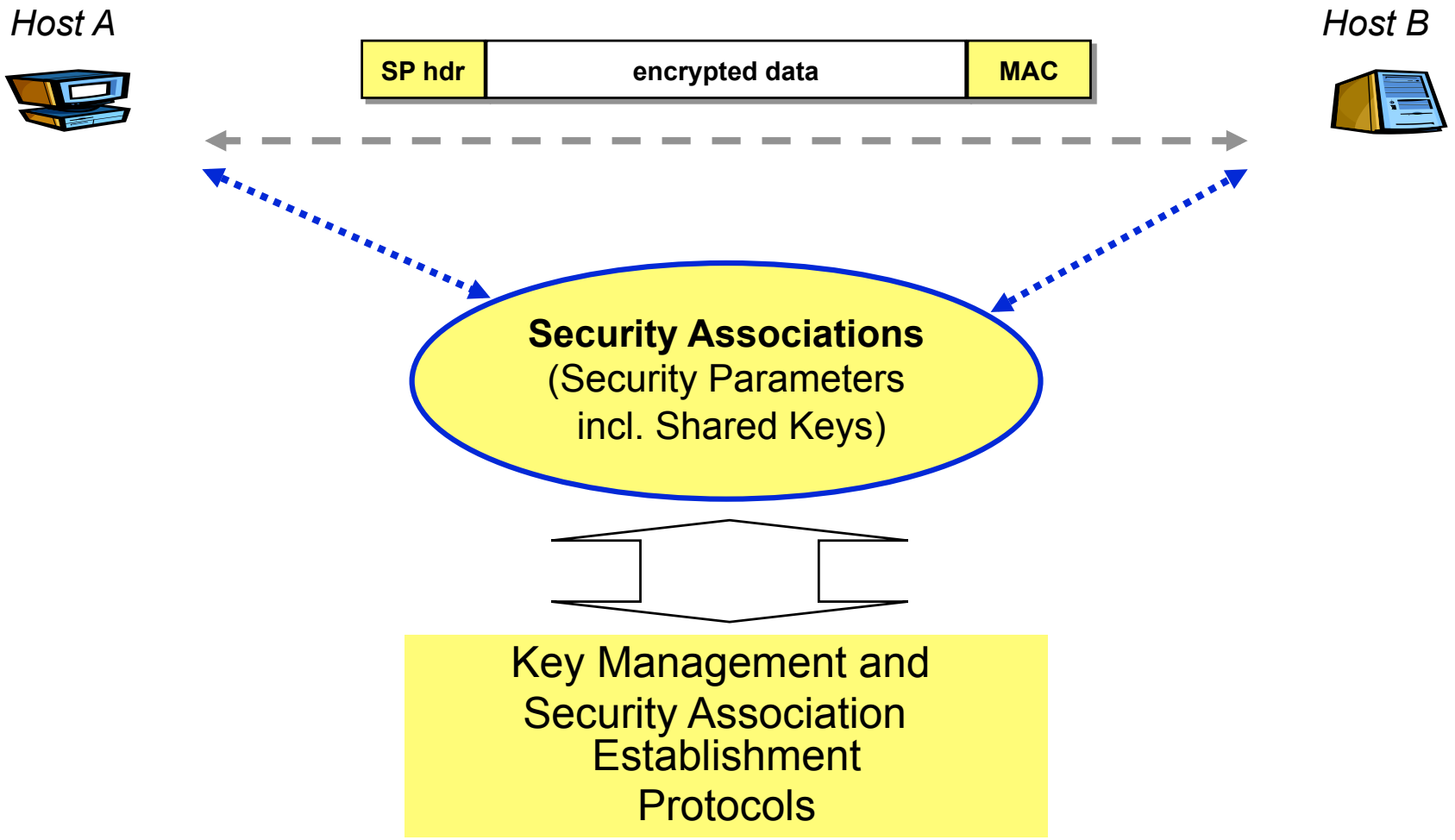
- Application layer:
  - closer to user
  - more sophisticated/granular controls
  - end-to-end
  - but what about firewalls?
- Lower layer:
  - application independent
  - hide traffic data
  - but vulnerable in middle points
- Combine?

SP Architecture I: Encapsulation



- Bulk data: symmetric cryptography
- Authenticated encryption: best choice is to authenticate the ciphertext

SP Architecture II: Session (Association) Establishment



Algorithm Selection

"a la carte“

- each algorithm (encryption, integrity protection, pseudo-random function, Diffie-Hellman group, etc.) is negotiated independently
- less compact to encode
- more flexible

- e.g., IKEv1

“suite”

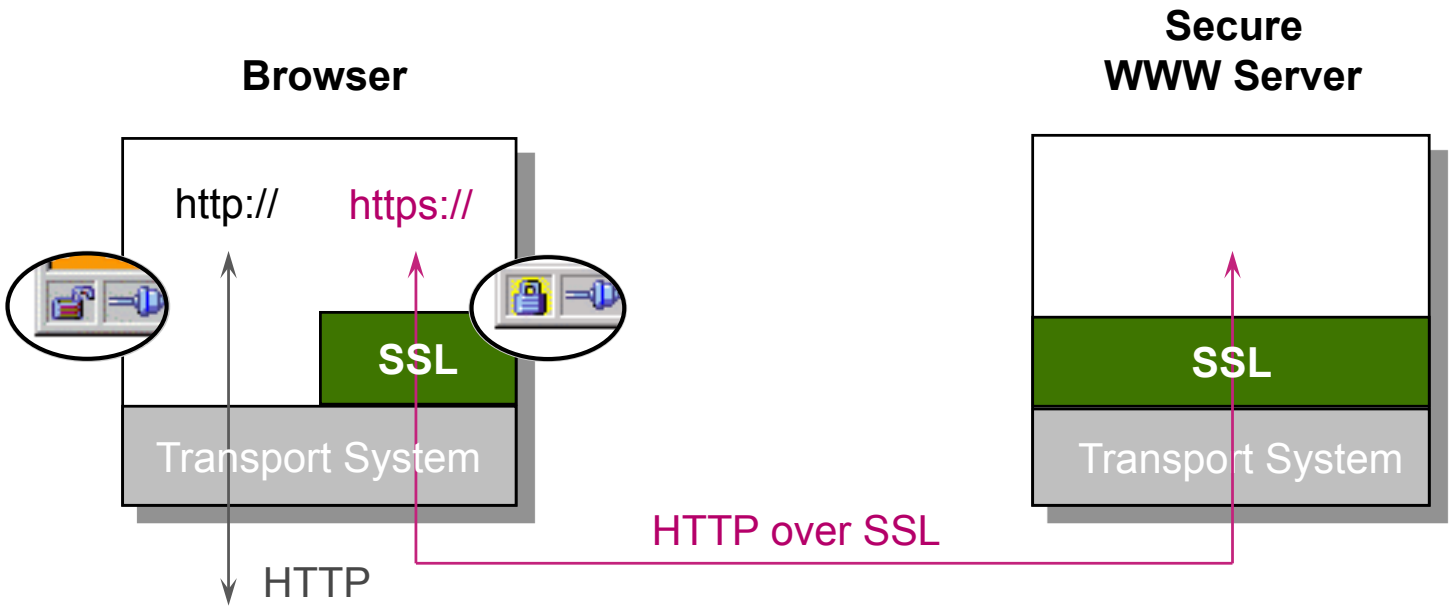
- all parameters are encoded into a single suite number; negotiation consists of offering one or more suites and having the other side choose
- simpler and more compact to encode
- potentially exponential number of suites
- less flexible

- e.g., TLS and IKEv2

Transport layer security

SSL / TLS

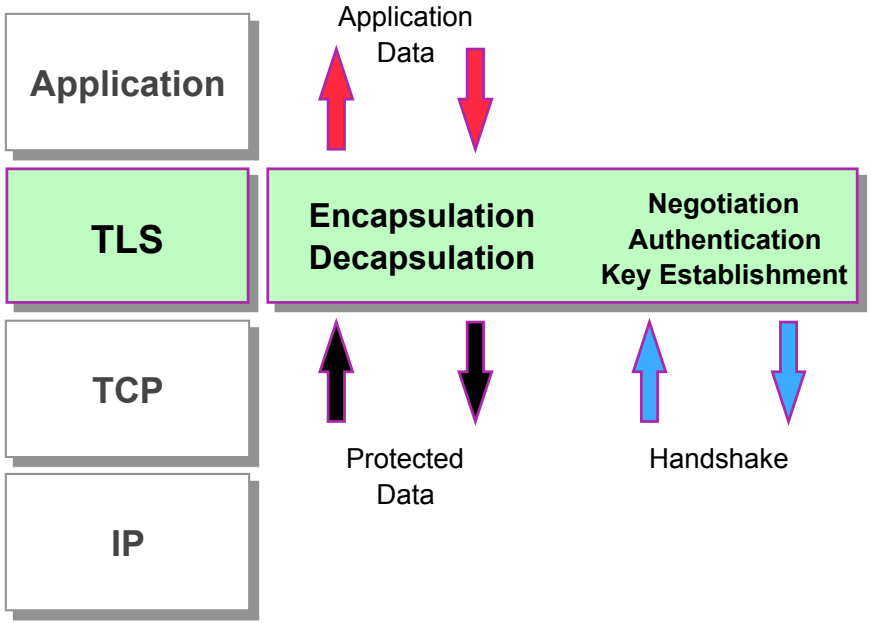
SSL/TLS Protocols



– connection-oriented data confidentiality and integrity, and optional client and server authentication.

Transport Layer Security Protocols

- IETF Working Group:
  Transport Layer Security (tls)
  - RFC 2246 (PS), 01/99
- transparent secure channels independent of the respective application.
- available protocols:
  - *Secure Shell* (SSH), SSH Ltd.
  - *Secure Sockets Layer* (SSL), Netscape
  - *Transport Layer Security* (TLS), IETF



SSL / TLS

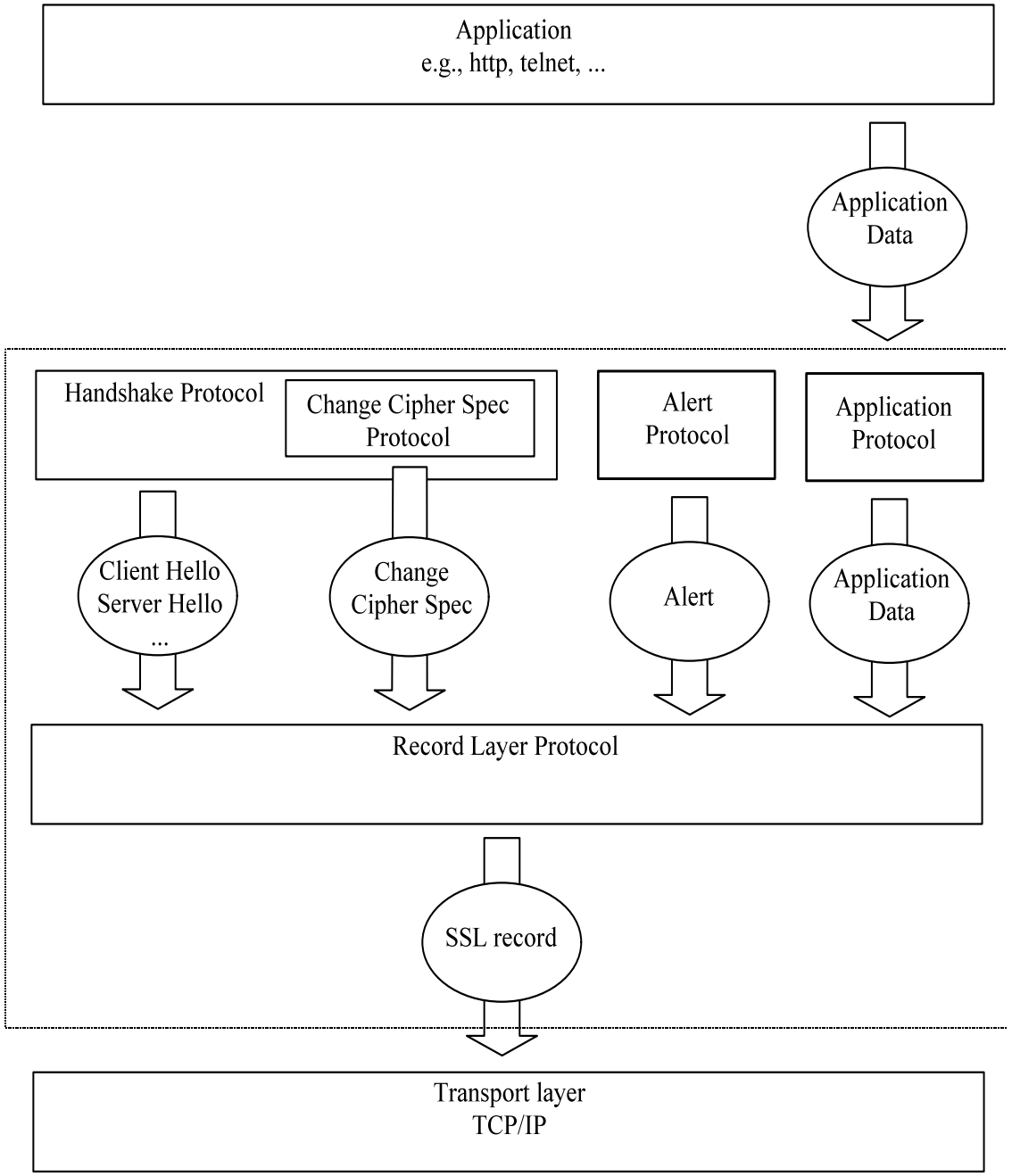
- Mainly in context of WWW security, i.e., to secure the HyperText Transfer Protocol (HTTP)
- But, in between application layer and TCP, thus can be used to secure other applications than HTTP too (IMAP, telnet, ftp, …)

Other WWW security protocols

- PCT: Microsoft's alternative to SSL
- S-HTTP: S/MIME-like protocol
- SET: for credit card transactions
- XML-Signature: PKCS#7-based signature on XML documents
- ...

SSL / TLS

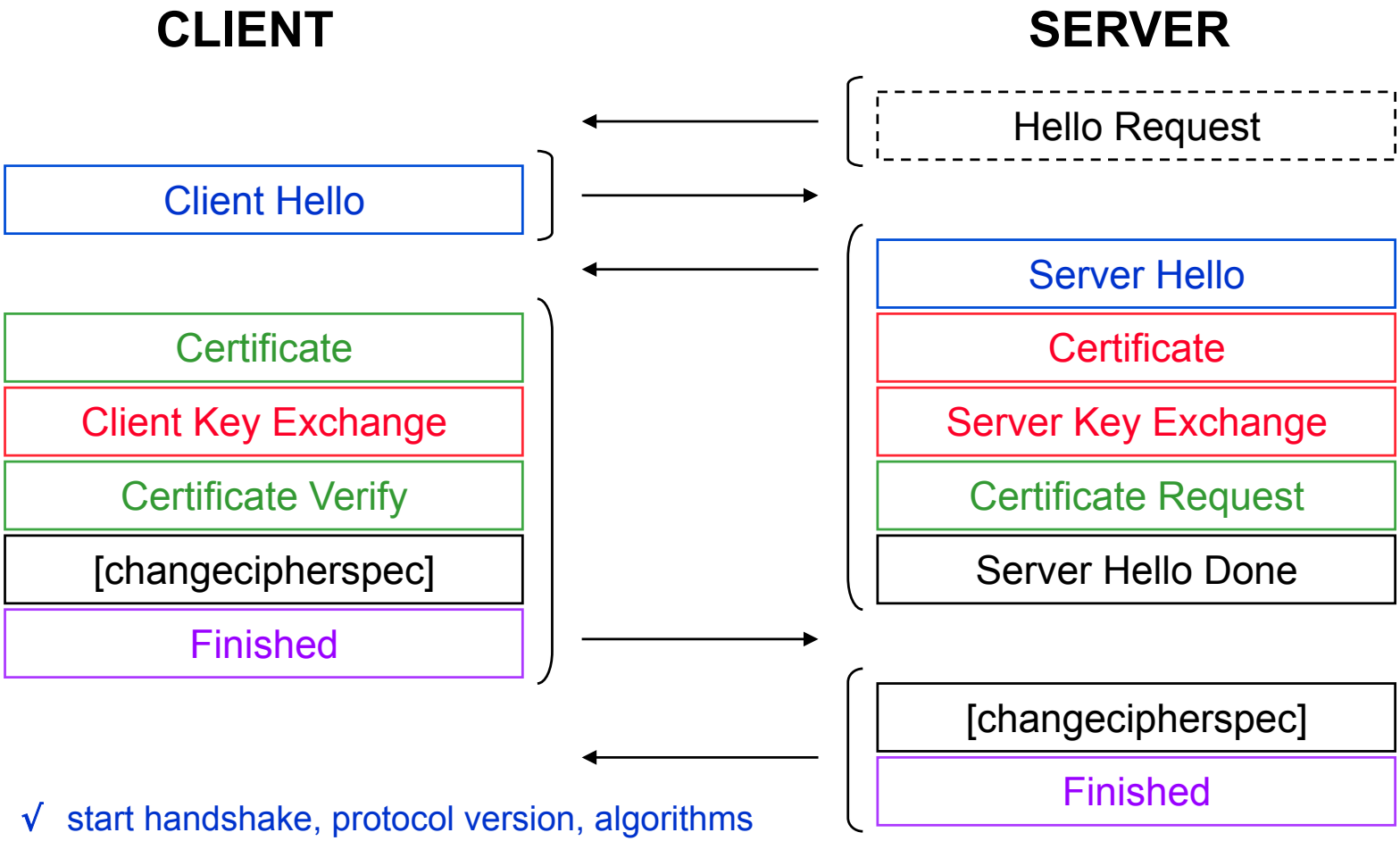
- "Secure Sockets Layer" (Netscape)
  - SSL 2.0: security flaws!
  - SSL 3.0: still widely used - not interoperable with TLS 1.0
- "Transport Layer Security" (IETF)
  - TLS 1.0: adopted SSL 3.0 with minor changes
  - RFC 2246, 01/99 (PS)
- TLS: security at the transport layer
  - can be used (and is intended) for other applications too
  - end-to-end secure channel, but nothing more...
  - data is only protected during communication
  - no non-repudiation!


Application
e.g., http, telnet, ...
Application Data
Handshake Protocol
Change Cipher Spec Protocol
Alert Protocol
Application Protocol
Client Hello
Server Hello
...
Change Cipher Spec
Alert
Application Data
Record Layer Protocol
SSL record
Transport layer
TCP/IP

SSL/TLS in more detail

- "Record layer" protocol
  - fragmentation
  - compression (not in practice)
  - cryptographic security:
    - encryption → data confidentiality
    - MAC → data authentication [no digital signatures!]
- "Handshake" protocol
  - client and server authentication
  - establish cryptographic keys (for encryption and MAC)
  - negotiation of cryptographic algorithms

Handshake: overview



- √ start handshake, protocol version, algorithms
- √ authentication server + exchange (pre)master secret
- √ client authentication
- √ end handshake, integrity verification

TLS 1.0 Data Encapsulation Options

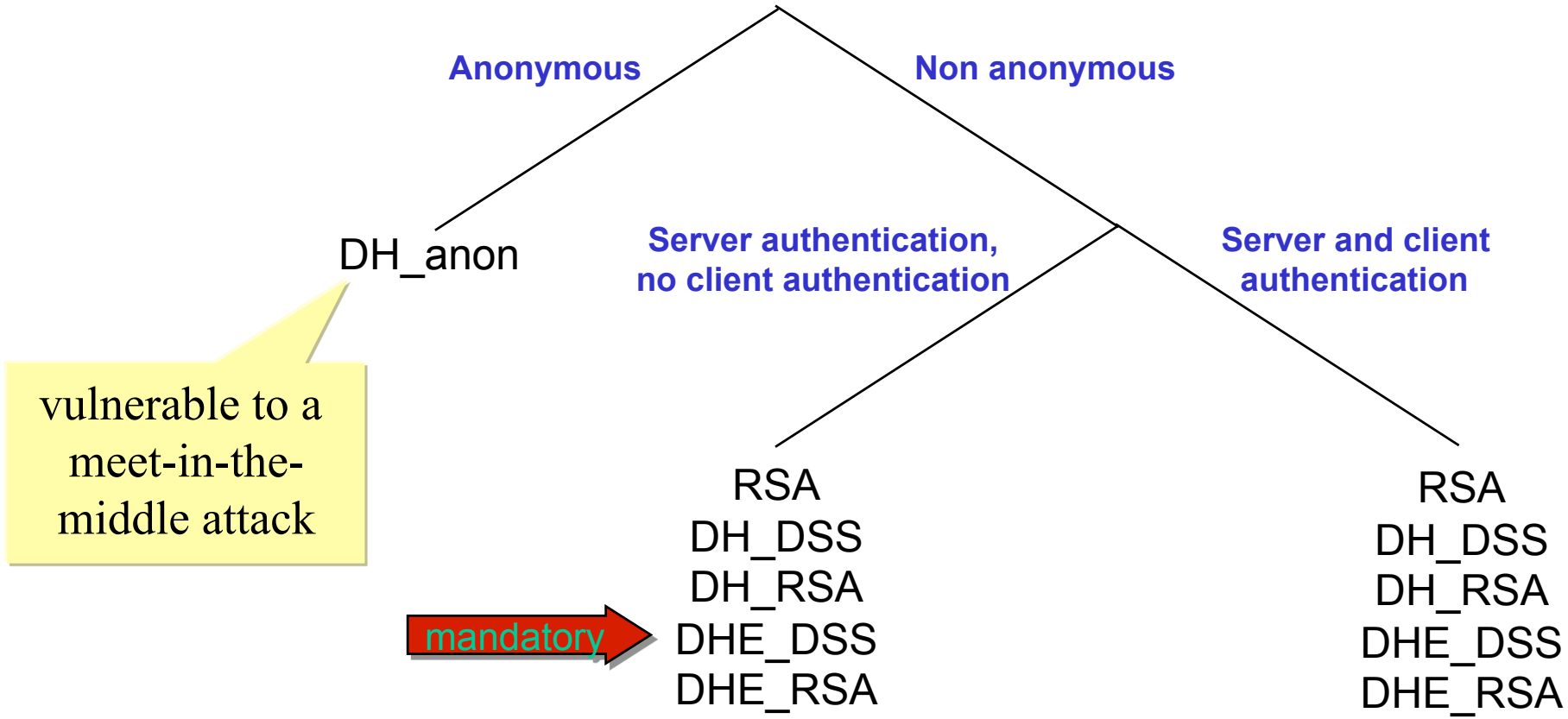
Integrity		
key size	144	160
algorithm options	HMAC-MD5	HMAC-SHA

mandatory

Confidentiality				
key size	40	56	128	168
algorithm options	RC4_40 RC4_40 RC2_CBC_40 DES_CBC_40	DES_CBC	RC4 IDEA_CBC	3DES_EDE_CBC

mandatory

TLS 1.0 Key Management Options



RFC 3268: AES Ciphersuites for TLS 06/2002

CipherSuite	Key Exchange	Certificate Type
TLS_RSA_WITH_AES_128_CBC_SHA	RSA	RSA
TLS_DH_DSS_WITH_AES_128_CBC_SHA	DH_DSS	DSS
TLS_DH_RSA_WITH_AES_128_CBC_SHA	DH_RSA	RSA
TLS_DHE_DSS_WITH_AES_128_CBC_SHA	DHE_DSS	DSS
TLS_DHE_RSA_WITH_AES_128_CBC_SHA	DHE_RSA	RSA
TLS_DH_anon_WITH_AES_128_CBC_SHA	DH_anon	
TLS_RSA_WITH_AES_256_CBC_SHA	RSA	RSA
TLS_DH_DSS_WITH_AES_256_CBC_SHA	DH_DSS	DSS
TLS_DH_RSA_WITH_AES_256_CBC_SHA	DH_RSA	RSA
TLS_DHE_DSS_WITH_AES_256_CBC_SHA	DHE_DSS	DSS
TLS_DHE_RSA_WITH_AES_256_CBC_SHA	DHE_RSA	RSA
TLS_DH_anon_WITH_AES_256_CBC_SHA	DH_anon	

TLS 1.1

RFC 4346 April 2006

- Makes RSA with 3DES the mandatory cipher suite
  - TLS 1.1: TLS_RSA_WITH_3DES_EDE_CBC_SHA
  - TLS 1.0: TLS_DHE_DSS_WITH_3DES_EDE_CBC_SHA
- Provides several fixes, including
  - for the Rogaway and Vaudenay CBC attacks
  - for the Vaudenay, Boneh-Brumley, and KPR attacks

TLS 1.2

RFC 5246 - August 2008

- reduces dependency on MD5 and SHA-1
- add support for authenticated encryption
- add AES ciphersuites

SSL/TLS: security services

SSL/TLS *only* provides:

- entity authentication
- data confidentiality
- data authentication

SSL/TLS does *not* provide:

- non-repudiation
- unobservability (identity privacy)
- protection against traffic analysis
- secure many-to-many communications (multicast)
- security of the end-points (but relies on it!)

SSL/TLS: security ?

- SSL/TLS offers an adequate security level but it is a very complex protocol

- TLS 1.x is the result of a public reviewing process: several problems have been identified in earlier versions (SSL 2.0/3.0) and have been solved

- Limited deployment of 1.1 and almost none of 1.2

SSL/TLS: evaluation

Some remaining security problems though

- bad implementation; e.g., random number generation
- PKCS#1 attack is patched (use other padding scheme: OAEP; server error messages should contain less information)
- version / cipher suite roll back attempts now patched (due to backward compatibility; disable export algorithms if possible)
- traffic analysis: e.g., length of ciphertext might reveal useful info
- PKI issues: revocation, root keys, certificate parsing,…
- Web spoofing and phishing
- plenty of known plaintext (both SSL/TLS and HTTP related)

TLS Renegotiation attack

[Marsh Ray 9 November 2009]

- Cipher suite can be renegotiated dynamically throughout the session
  - Negotiation and renegotiation look the same
- Person-In-The-Middle can inject (plaintext) traffic in a protected session as if it came from a client
  - establishes an unauthenticated session with a server
  - proxies another authenticated session between the client victim and the same server
  - triggers a renegotiation
  - server: last message received from attacker prior to renegotiation is attached to first message received from client after renegotiation

TLS renegotiation indication extension

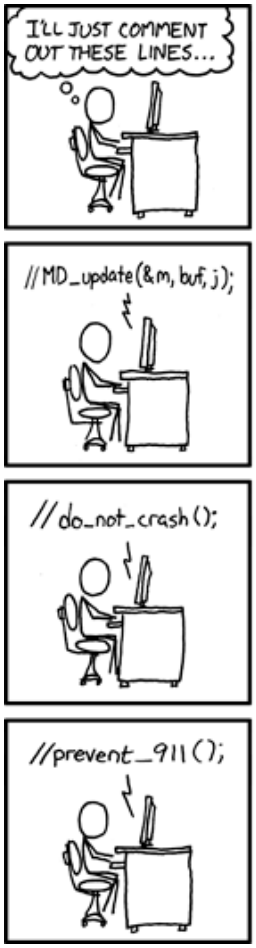
RFC 5746 – February 2010

Implementation attacks

Debian-OpenSSL incident [13 May 2008]

https://cseweb.ucsd.edu/~hovav/dist/debiankey.pdf

- Weak key generation:
  only 32K keys
  - easy to generate all private keys
  - collisions
- Between 13-17 May 2008
  280 bad keys out of 40K
  (0.6%)
- Revocation problematic



IN THE RUSH TO CLEAN UP THE DEBIAN-OPENSSL FIASCO, A NUMBER OF OTHER MAJOR SECURITY HOLES HAVE BEEN UNCOVERED:

AFFECTED SYSTEM	SECURITY PROBLEM
FEDORA CORE	VULNERABLE TO CERTAIN DECODER RINGS
XANDROS (EEE PC)	GIVES ROOT ACCESS IF ASKED IN STERN VOICE
GENTOO	VULNERABLE TO FLATTERY
OLPC OS	VULNERABLE TO JEFF GOLDBLUM'S POWERBOOK
SLACKWARE	GIVES ROOT ACCESS IF USER SAYS ELVISH WORD FOR "FRIEND"
UBUNTU	TURNS OUT DISTRO IS ACTUALLY JUST WINDOWS VISTA WITH A FEW CUSTOM THEMES

TLS certificate "NULL" issue.

- [Moxie Marlinspike'09] Black Hat
  - browsers may accept bogus SSL certs
  - CAs may sign malicious certs
- certificate for www.paypal.com\0.kuleuven.be will be issued if the request comes from a kuleuven.be admin
- response by PayPal: suspend Moxie's account
  - http://www.theregister.co.uk/2009/10/06/paypal_banishes_ssl_hacker/

Security in transport layer

- Transparent for application
- Pro: can be used for all TCP-based applications, without modifying them
- Con: authentication is one, but who/what to trust, is important
- Non-repudiation?
- In practice: (partially) integrated in application

Non-repudiation

- Strictly speaking only if in application, thus not provided by SSL/TLS
- SSL/TLS secures the communication channel, but not the exchanged messages
- SSL/TLS does not use digital signatures in the first place (except for client authentication)
- For electronic business, more advanced security protocols are needed...

User authentication

First *authentication*, then *authorization* !

SSL/TLS client authentication:

- during handshake, client digitally signs a specific message that depends on all relevant parameters of secure session with server
- software devices, smart cards or USB tokens can be deployed through standardized cryptographic interfaces supported by browsers
  (Netscape: PKCS#11; MSIE: PC/SC)
- PKCS#12 key container provides software mobility

Usually another mechanism on top of SSL/TLS

TLS in the future (1)

- TLS 2.0?
- Some possible TLS enhancements, discussed within the IETF TLS WG:
  - RSA-OAEP
  - identity protection [note that this is already indirectly possible by authenticating within a DH_anon session]
  - cipher suites for compression
  - missing cipher suites (not all combinations possible)
- Backward compatibility remains very important!

TLS in the future (2)

Enhancements proposed in literature

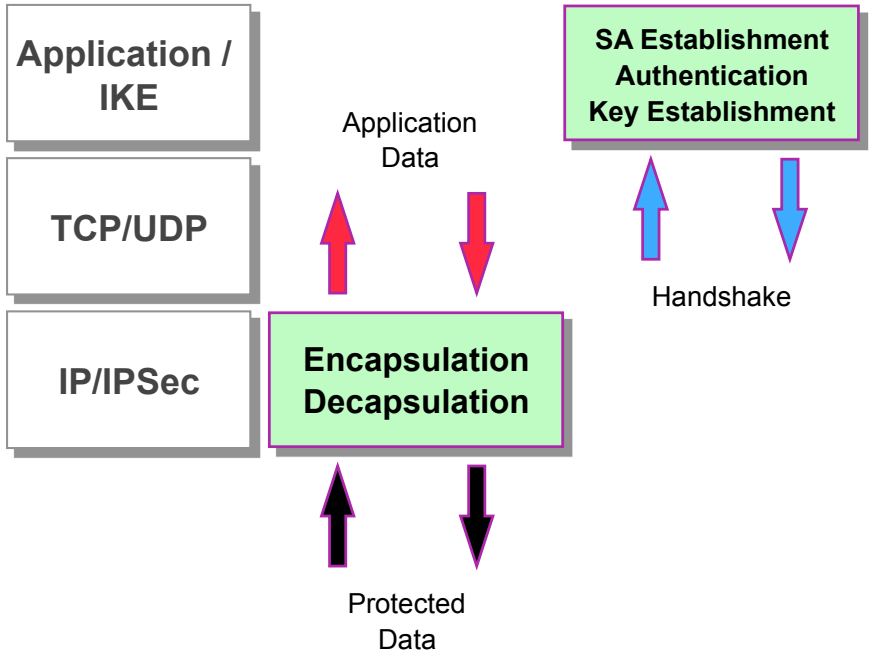
- performance improvements:
  'batching' [ShachamBoneh'01] and 'fast-track' [ShachamBoneh'02]
- user (identity) privacy [PersianoVisconti'00]
- client puzzles [DeanStubblefield'01] to counter denial-of-service attacks
- trust negotiation [Hess et al'02]

Network layer security

IPsec, VPN, SSH

IP Security Protocols

- IETF Working Group:
  IP Security Protocol (ipsec)
  Security Architecture for the Internet Protocol
  - RFC 2401 (PS), 11/98
- ***IP Authentication Header (AH)***
  - RFC 2402 (PS), 11/98
- ***IP Encapsulating Security Payload (ESP)***
  - RFC 2406 (PS), 11/98
- ***Internet Key Exchange (IKE)***
  - RFC 2409 (PS), 11/98
  - Application layer protocol for negotiation of Security Associations (SA) and Key Establishment



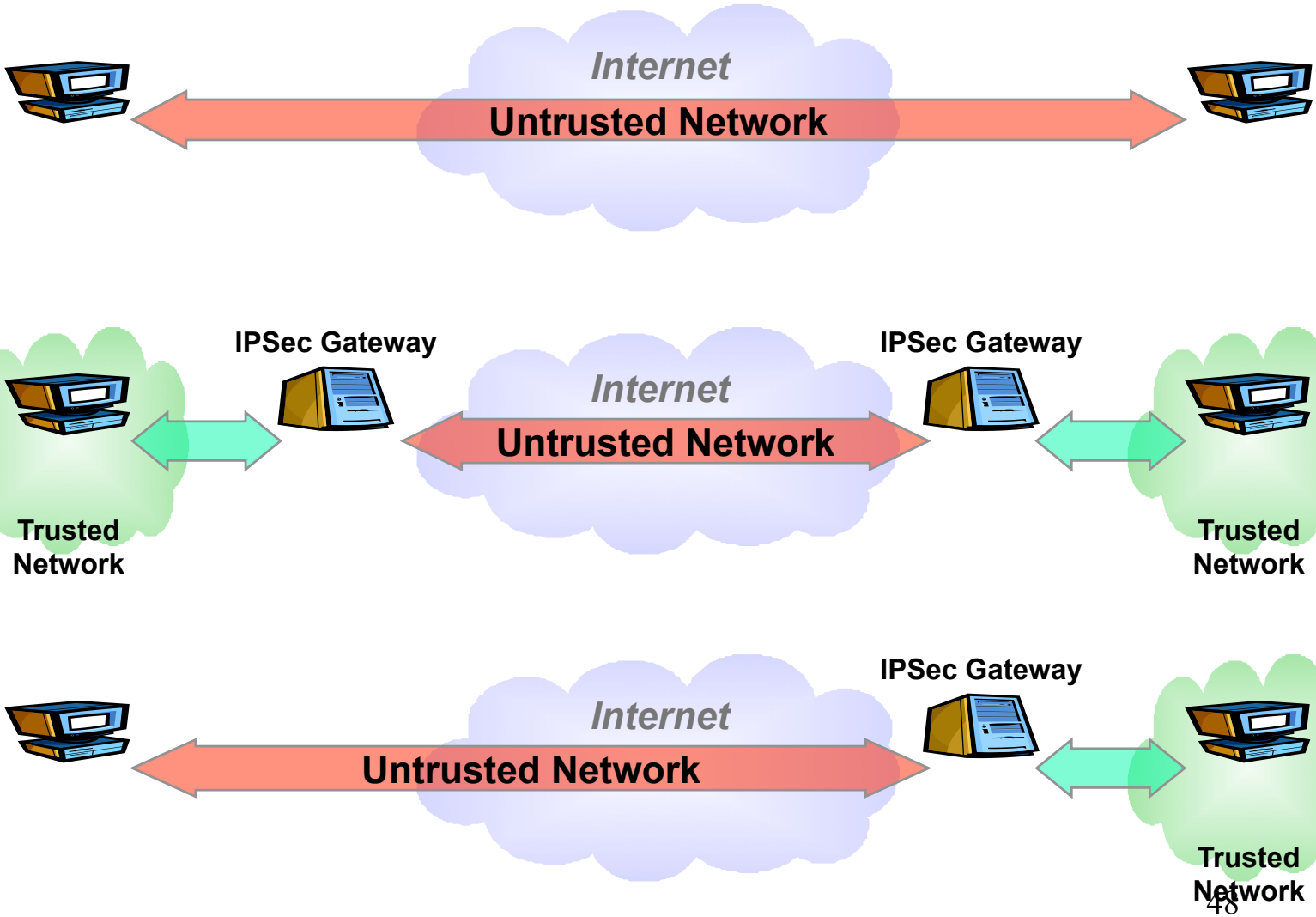
- **Large and complex……. (48 documents)**
- **Mandatory for IPv6, optional for IPv4**

IPSec VPN models: Hosts and Security Gateways

Host-to-host (not VPN)

Branch-to-branch

Host-to-gateway



IPsec - Security services

- Access control
- Connectionless integrity
- Data origin authentication
- Rejection of replayed packets (a form of partial sequence integrity)
- Confidentiality
- Limited traffic flow confidentiality

IPsec - Concepts

- Security features are added as extension headers that follow the main IP header
  - Authentication header (AH)
  - Encapsulating Security Payload (ESP) header
- Security Association (SA)
  - Security Parameter Index (SPI)
  - IP destination address
  - Security Protocol Identifier (AH or ESP)

IPsec - Parameters

- sequence number counter
- sequence counter overflow
- anti-replay window
- AH info (algorithm, keys, lifetimes, ...)
- ESP info (algorithms, keys, IVs, lifetimes, ...)
- lifetime
- IPSec protocol mode (tunnel or transport)
- path MTU (maximum transmission unit)

IKE Algorithm Selection
Mandatory Algorithms

Algorithm Type	IKE v1	IKE v2
Payload Encryption	DES-CBC	**AES-128**-CBC
Payload Integrity	HMAC-MD5 HMAC-SHA1	HMAC-SHA1
DH Group	768 Bit	**1536** Bit
Transfer Type 1 (Encryption)	ENCR_DES_CBC	ENCR_**AES_128**_CBC
Transfer Type 2 (PRF)	PRF_HMAC_SHA1 [RFC2104]	PRF_HMAC_SHA1 [RFC2104]
Transfer Type 3 (Integrity)	AUTH_HMAC_SHA1_96 [RFC2404]	AUTH_HMAC_SHA1_96 [RFC2404]

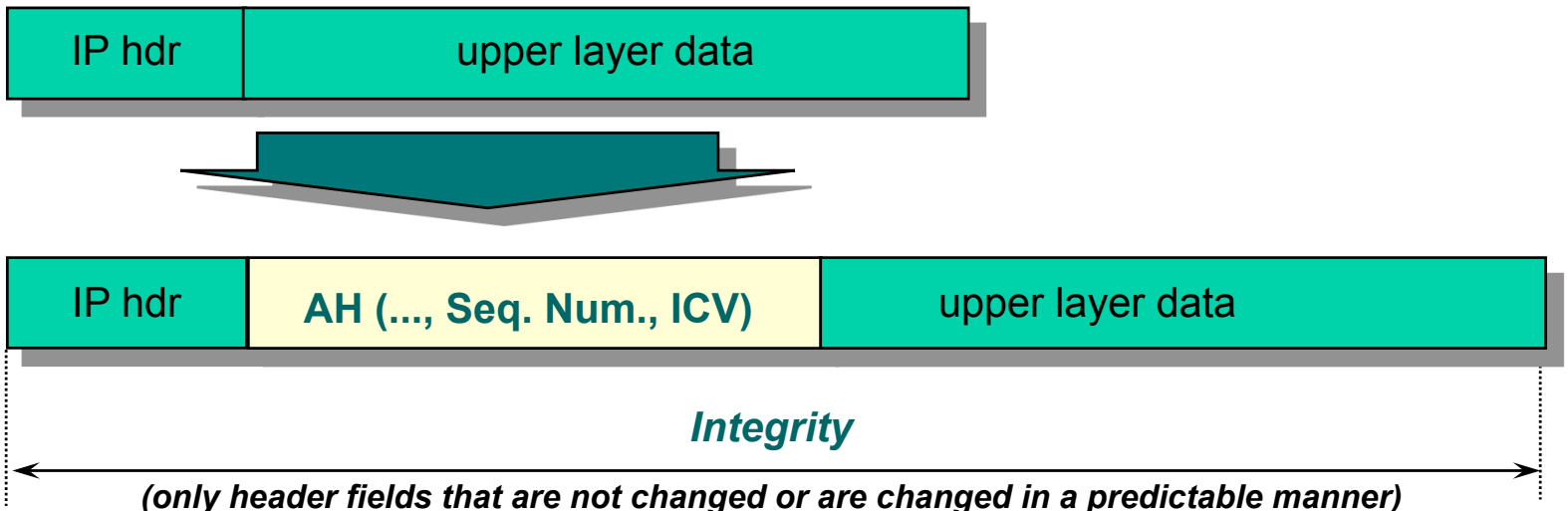
Source: draft-ietf-ipsec-ikev2-algorithms-00.txt, May 2003

IPsec - Modes

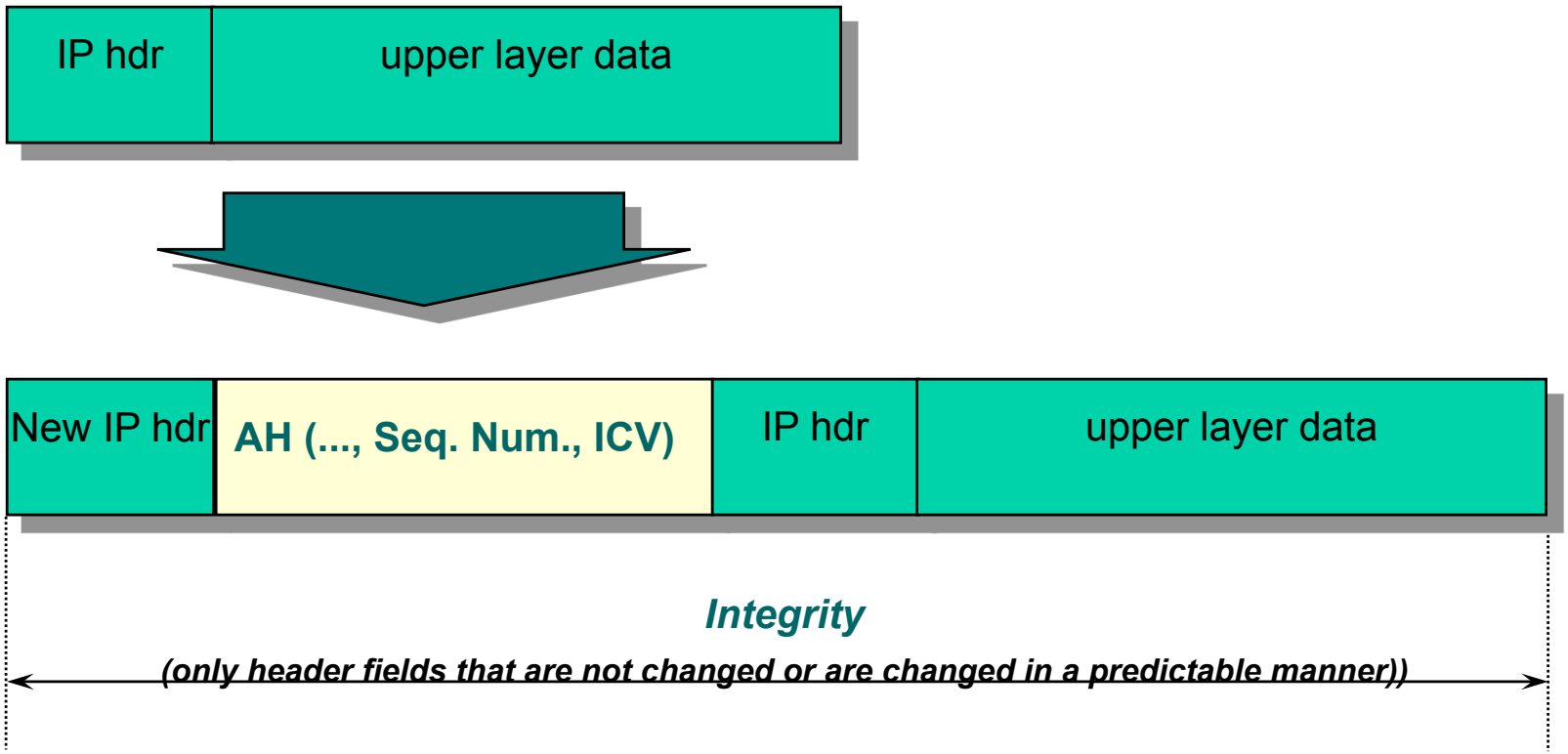
- Transport *(host-to-host)*
  - ESP: encrypts and optionally authenticates IP payload, but not IP header
  - AH: authenticates IP payload and selected portions of IP header
- Tunnel *(between security gateways)*
  - after AH or ESP fields are added, the entire packet is treated as payload of new outer IP packet with new outer header
  - used for VPN

IPsec - AH Transport mode

- Security Parameters Index: identifies SA
- Sequence number: anti-replay
- Integrity Check Value: data authentication using HMAC-SHA-1-96 or HMAC-MD5-96



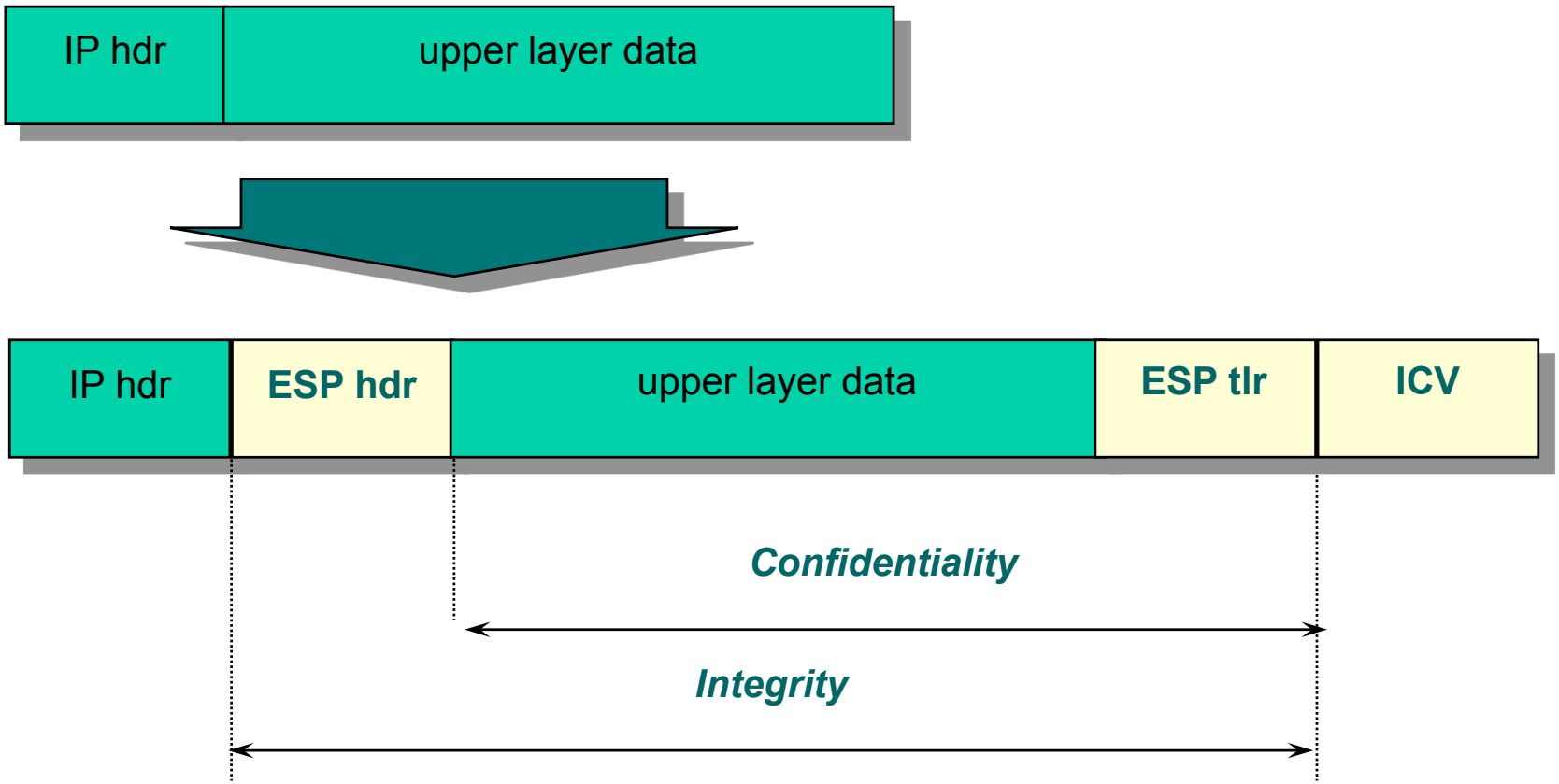
IPsec - AH Tunnel mode



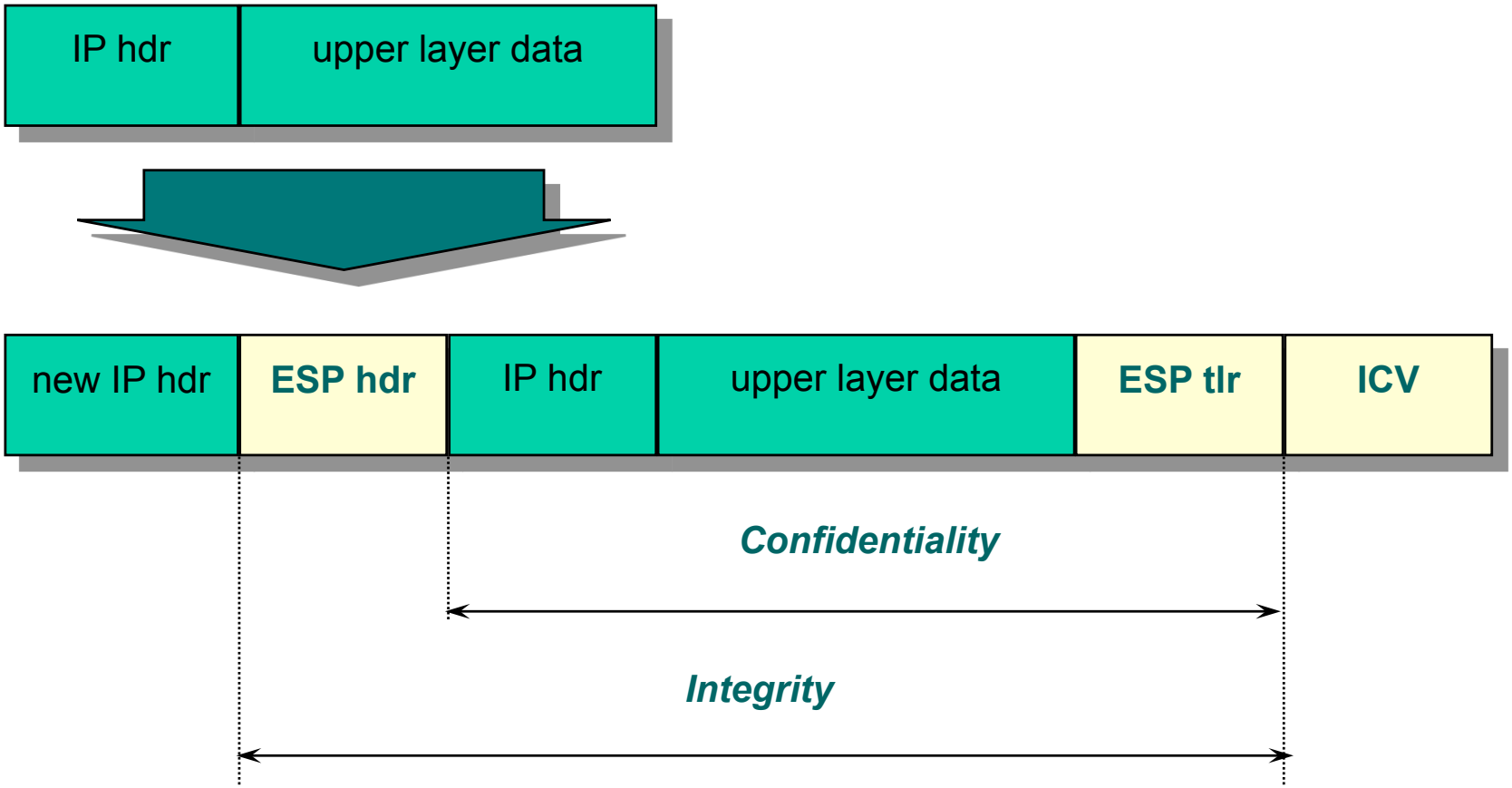
IPsec - ESP header

- Security Parameters Index: identifies SA
- Sequence number: anti-replay
- Encrypted payload data: data confidentiality using DES, 3DES, RC5, IDEA, CAST, Blowfish
- Padding: required by encryption algorithm (additional padding to provide traffic flow confidentiality)
- Integrity Check Value : data authentication using HMAC-SHA-1-96 or HMAC-MD5-96

IPsec - ESP Transport mode



IPsec - ESP Tunnel mode



IPsec: Key management

- RFCs 2407, 2408, and 2409
- Manual
- Automated
  - procedure / framework
    - Internet Security Association and Key Management Protocol (ISAKMP), RFC 2408 (PS)
  - key exchange mechanism: Internet Key Exchange (IKE)
    - Oakley: DH + cookie mechanism to thwart clogging attacks
    - SKEME

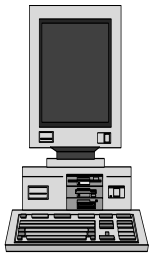
IPsec: Key management

- IKE defines 5 exchanges
  - Phase 1: establish a secure channel
    - Main mode
    - Aggressive mode
  - Phase 2: negotiate IPSEC security association
    - Quick mode (only hashes, PRFs)
  - Informational exchanges: status, new DH group
- based on 5 generic exchanges defined in ISAKMP
- cookies for anti-clogging

IPsec: Key management

- protection suite (negotiated)
  - encryption algorithm
  - hash algorithm
  - authentication method:
    - preshared keys, DSA, RSA, encrypted nonces
  - Diffie Hellman group: 5 possibilities

IKE - Main Mode with Digital Signatures



Initiator

Responder

proposed attributes →

← selected attributes

g^x, N_i →

← g^y, N_r

K derived from
master = prf(N_i || N_r, g^{xy})

SIG_i = Signature on
H(master, g^x || g^y || ... || ID_i)

E(K, ID_i, [Cert(i)], SIG_i) →

SIG_r = Signature on
H(master, g^y || g^x || ... || ID_r)

← E(K, ID_r, [Cert(r)], SIG_r)

H is equal to prf or the hash function tied to the signature algorithm
(all inputs are concatenated)

IKE - Main Mode with Digital Signatures

- mutual entity authentication
- mutual implicit and explicit key authentication
- mutual key confirmation
- joint key control
- identity protection
- freshness of keying material
- perfect forward secrecy of keying material
- non-repudiation of communication
- cryptographic algorithm negotiation

IKE v2 - RFC Dec 2005

- IKEv1 implementations incorporate additional functionality including features for NAT traversal, legacy authentication, and remote address acquisition, not documented in the base documents
- Goals of the IKEv2 specification include
  - to specify all that functionality in a single document
  - to simplify and improve the protocol, and to fix various problems in IKEv1 that had been found through deployment or analysis
- IKEv2 preserves most of the IKEv1 features while redesigning the protocol for efficiency, security, robustness, and flexibility

IKE v2 Initial Handshake (1/2)

- Alice and Bob negotiate cryptographic algorithms, mutually authenticate, and establish a session key, creating an IKE-SA
- Usually consists of two request/response pairs
  - The first pair negotiates cryptographic algorithms and does a Diffie-Hellman exchange
  - The second pair is encrypted and integrity protected with keys based on the Diffie-Hellman exchange

IKE v2 Initial Handshake (2/2)

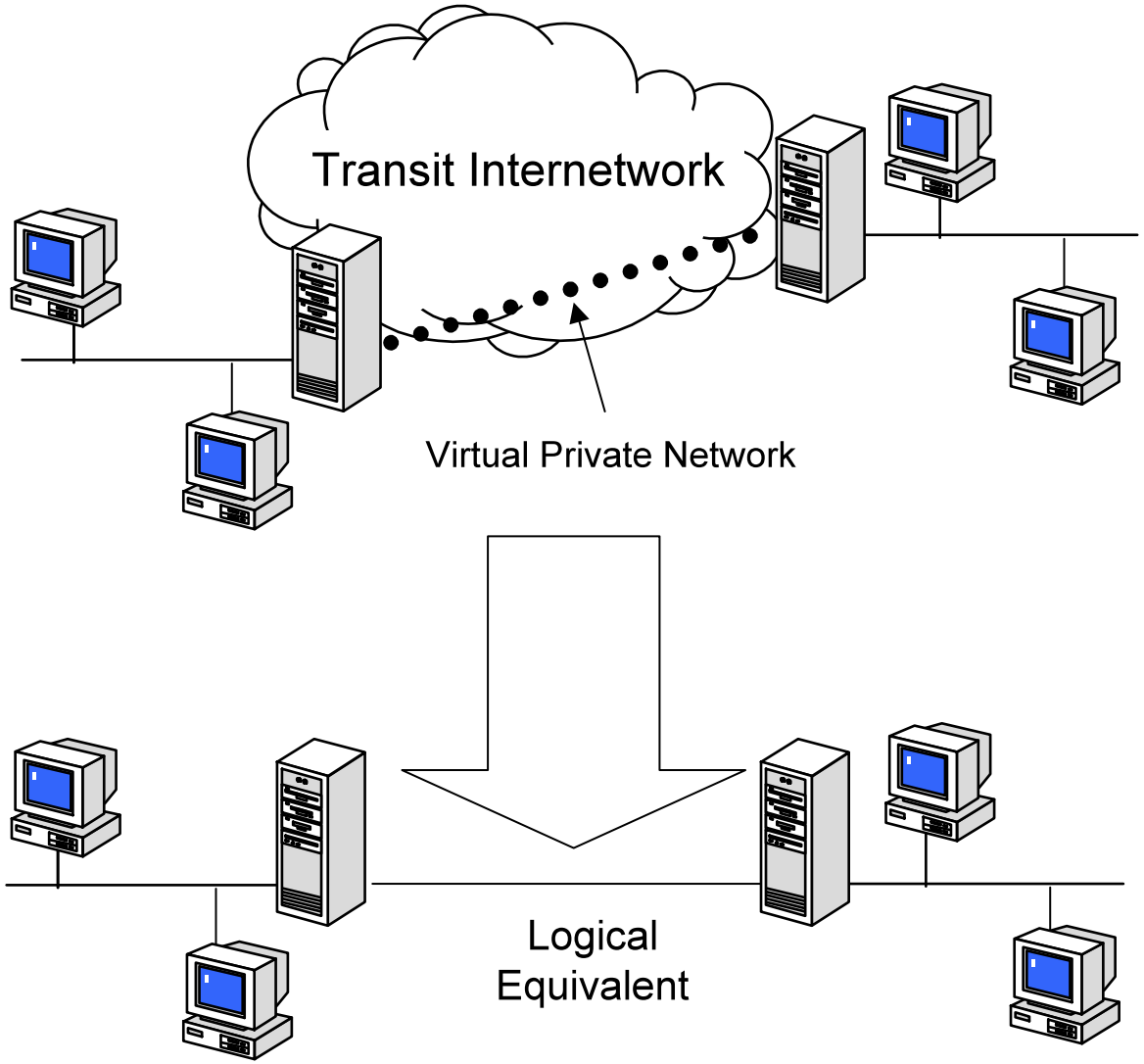
- Second exchange
  - divulge identities
  - prove identities using an integrity check based on the secret associated with their identity (private key or shared secret key) and the contents of the first pair of messages in the exchange
  - establish a first IPsec SA (“child-SA”) is during the initial IKE-SA creation

IPsec Overview

- Much better than previous alternatives
- IPsec documents hard to read
- Committee design: too complex
  - ESP in Tunnel mode probably sufficient
  - Simplify key management
  - Clarify cryptographic requirements
- …and thus difficult to implement (securely)
- avoid encryption without data authentication

VPN?

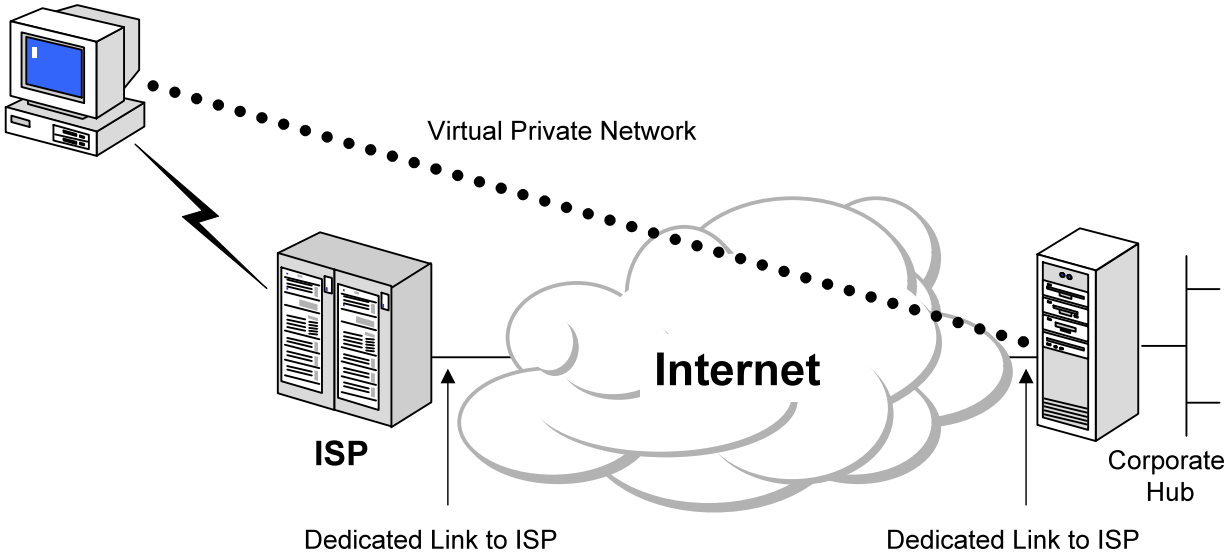
- Virtual Private Network
- Connects a private network over a public network.
- Connection is secured by tunneling protocols.
- The nature of the public network is irrelevant to the user.
- It appears as if the data is being sent over the private network.


Transit Internetwork
Virtual Private Network
Logical
Equivalent

VPN - Common use

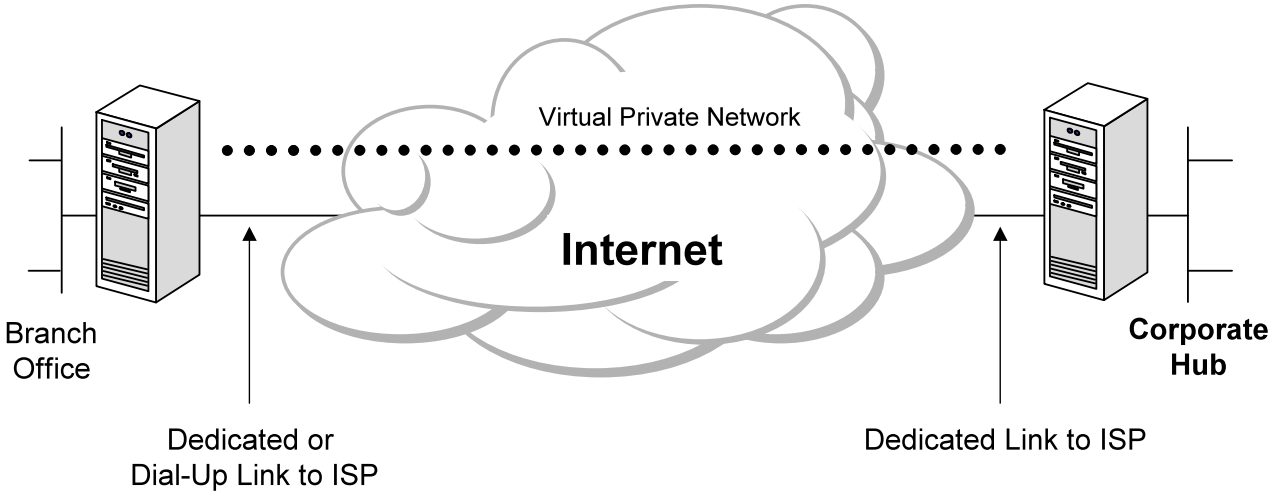
- Remote user access over the Internet
- Connecting networks over the Internet
- Connection computers over an intranet

Remote user access over the Internet



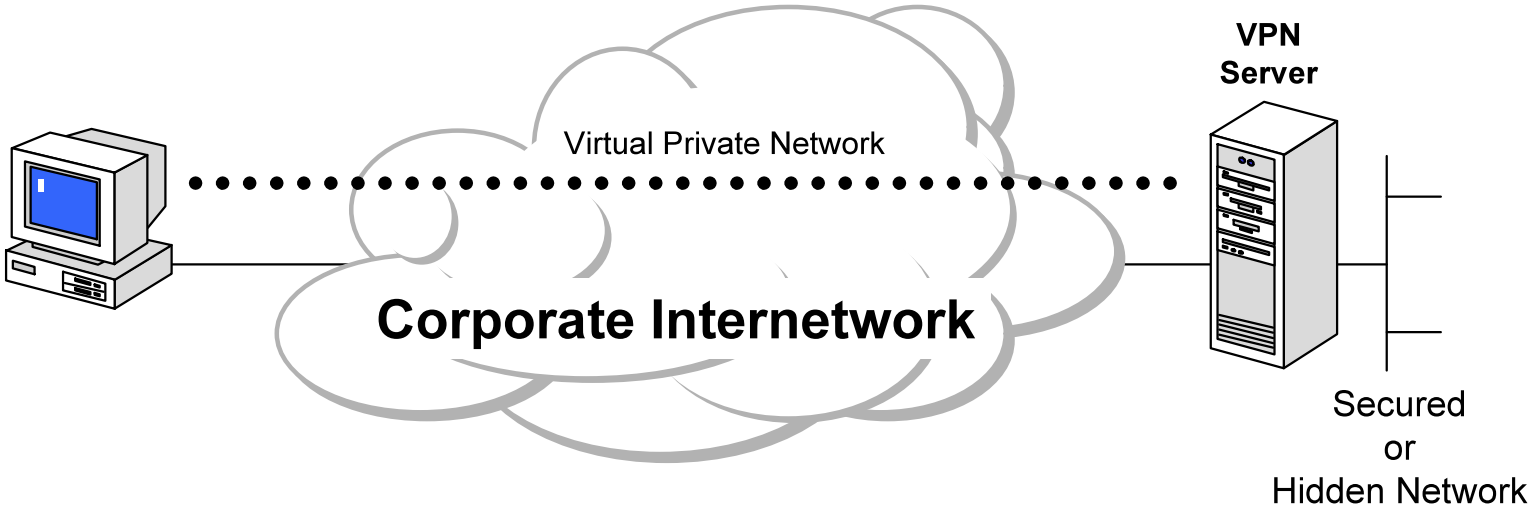
- You can use existing local Internet connections.
- No need for long distance connections

Connecting networks over the Internet



- You can use existing local Internet connections.
- No need for long distance connections or leased lines

Connecting computers over an intranet

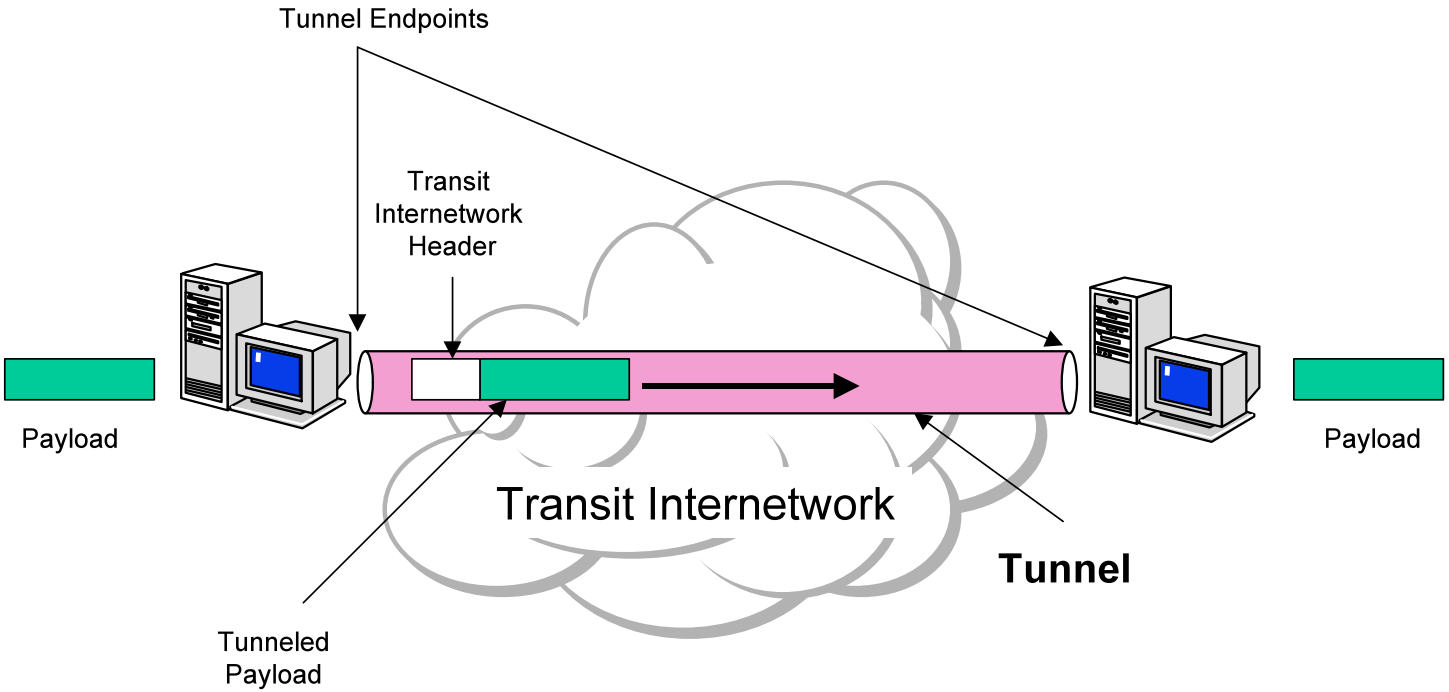


- Provides easy client access to secured or hidden networks within the corporate network

VPN - Basic requirements

- User authentication and user authorization
- Data authentication and data confidentiality
- Key management
- Encapsulation
  - data of private network is encapsulated in packets suited for transmission over the public network. (tunneling protocol)
- Address management
  - assign a client′s address on the private net

Tunneling


Tunnel Endpoints
Transit
Internetwork
Header
Payload
Payload
Transit Internetwork
Tunnel
Tunneled
Payload

Final remarks

Some observations

- IPSec is really transparent, SSL/TLS only conceptually, but not really in practice
- SSH, PGP: stand-alone applications, immediately and easy to deploy and use
- Network security: solved in principle
- Electronic commerce security: more is needed!

More information (1)

- William Stallings, *Cryptography and Network Security - Principles and Practice*, Fifth Edition, 2009
- N. Doraswamy, D. Harkins, *IPSec (2nd Edition*), Prentice Hall, 2003 (outdated)
- Erik Rescorla, SSL and TLS: *Designing and Building Secure Systems,* Addison-Wesley, 2000.
- IETF web site: www.ietf.org
  - e.g., IETF-TLS Working Group
    http://www.ietf.org/html.charters/tls-charter.html

More information (2)

- Jon C. Snader, *VPNs Illustrated: Tunnels, VPNs, and IPsec,* Addison-Wesley, 2005
- Sheila Frankel, *Demystifying the IPsec Puzzle*, Artech House Computer Security Series, 2001
- Anup Gosh, *E-Commerce Security, Weak Links, Best Defenses,* Wiley, 1998
- Rolf Oppliger, *Security Technologies for the World Wide Web,* Artech House Computer Security Series 1999
- W3C Security (incl WWW Security FAQ)

  http://www.w3.org/Security/