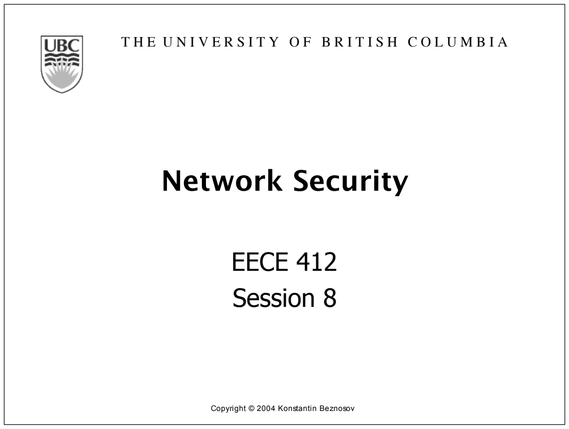

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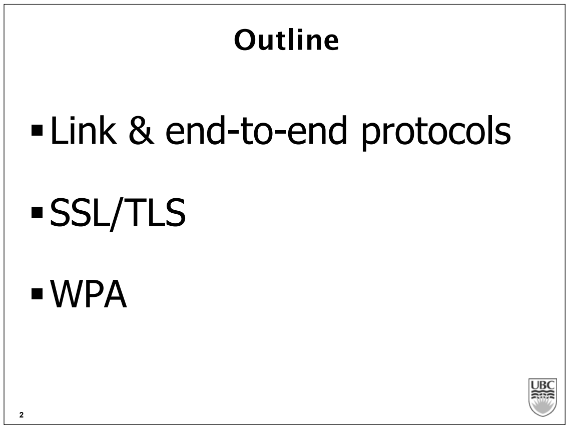
Network Security

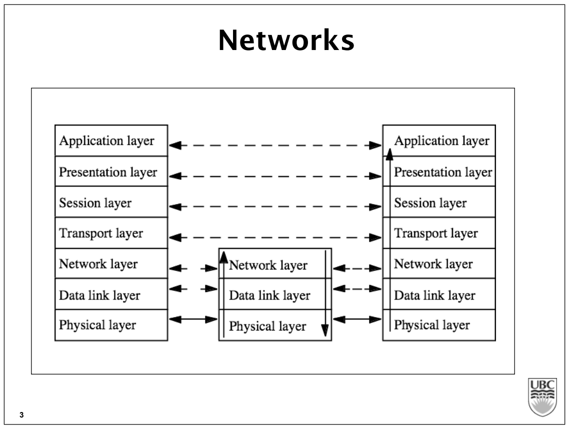
EECE 412
Session 8



Outline

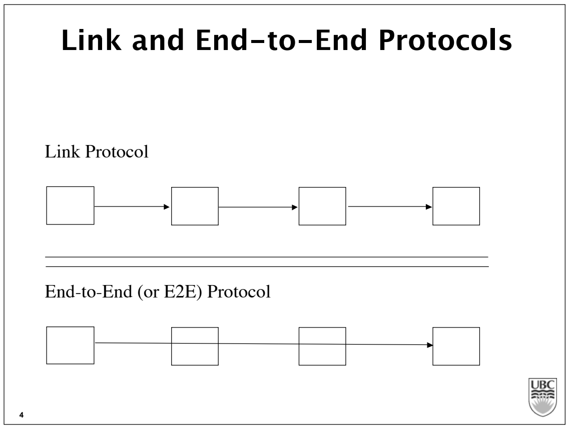
- Link & end-to-end protocols
- SSL/TLS
- WPA

2



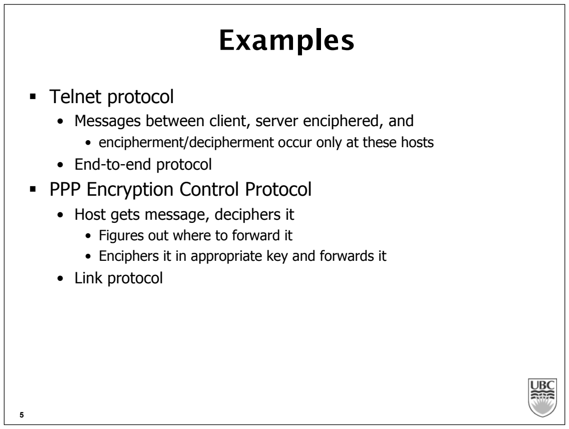
Networks

3



Link and End-to-End Protocols

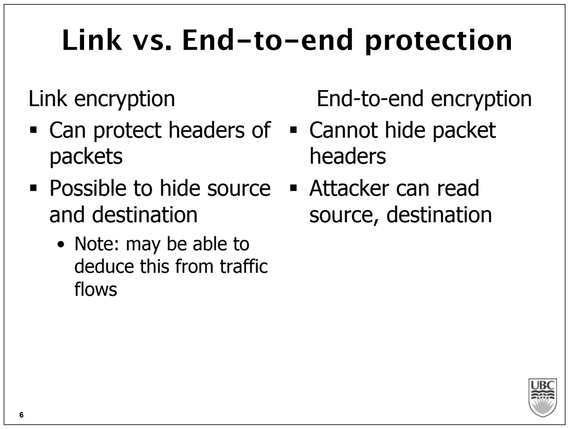
4



Examples

- Telnet protocol
  - Messages between client, server enciphered, and
    - encipherment/decipherment occur only at these hosts
  - End-to-end protocol
- PPP Encryption Control Protocol
  - Host gets message, deciphers it
    - Figures out where to forward it
    - Enciphers it in appropriate key and forwards it
  - Link protocol

5



Link vs. End-to-end protection

Link encryption

- Can protect headers of packets
- Possible to hide source and destination
  - Note: may be able to deduce this from traffic flows

End-to-end encryption

- Cannot hide packet headers
- Attacker can read source, destination

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Example Protocols

- Privacy-Enhanced Electronic Mail (PEM)
  - Applications layer protocol
  - Bishop
- Secure Socket Layer (SSL)/Transport Layer Security (TLS)
  - Transport layer protocol
- IP Security (IPSec)
  - Network layer protocol
  - Bishop
- Wi-Fi Protected Access (WPA)
  - Data layer protocol
  - Today session

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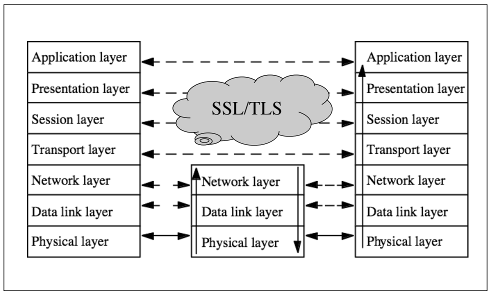
Secure Socket Layer (SSL)
a.k.a.
Transport Layer Security (TLS)

Networks



SSL Session

Association between two peers

- Two peers may have several sessions
- Information for each association:
  - Unique session identifier
  - Peer’s X.509v3 certificate, if needed
  - Compression method
  - Cipher spec for cipher and MAC
  - “Master secret” shared with peer
    - 48 bits

SSL Connection

Describes how data exchanged with peer in a session

- Several connections per session
- Information for each connection
  - Random data
  - Write keys (used to encipher data)
  - Write MAC key (used to compute MAC)
  - Initialization vectors (IVs) for ciphers, if needed
  - Sequence numbers

Supporting Crypto

- All parts of SSL use them
- Initial phase: public key system exchanges keys
  - Messages enciphered using classical ciphers, and MACed
  - Only certain combinations allowed
    - Depends on algorithm for key exchange cipher
  - Key exchange (a.k.a., interchange) algorithms:
    - RSA
    - Diffie-Hellman
    - Fortezza

RSA: Cipher, MAC Algorithms

Interchange cipher	*Classical cipher*	*MAC Algorithm*
RSA, key ≤ 512 bits	*none*	MD5, SHA
	RC4, 40-bit key	MD5
	RC2, 40-bit key, CBC mode	MD5
	DES, 40-bit key, CBC mode	SHA
RSA	*None*	MD5, SHA
	RC4, 128-bit key	MD5, SHA
	IDEA, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA

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D-H: Cipher, MAC Algorithms

Interchange cipher	*Classical cipher*	*MAC Algorithm*
Diffie-Hellman, DSS Certificate	DES, 40-bit key, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA
Diffie-Hellman, key ≤ 512 bits RSA Certificate	DES, 40-bit key, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA

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Fortezza: Cipher, MAC Algorithms

Interchange cipher	*Classical cipher*	*MAC Algorithm*
Fortezza key exchange	*none*	SHA
	RC4, 128-bit key	MD5
	Fortezza, CBC mode	SHA

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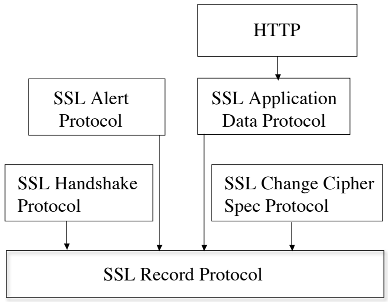
SSL Protocols



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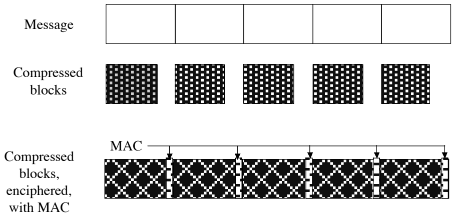
SSL Record Layer



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Overview of Handshake Rounds

1. Create SSL connection between client, server
2. Server authenticates itself
3. Client validates server, begins key exchange
4. Acknowledgments all around

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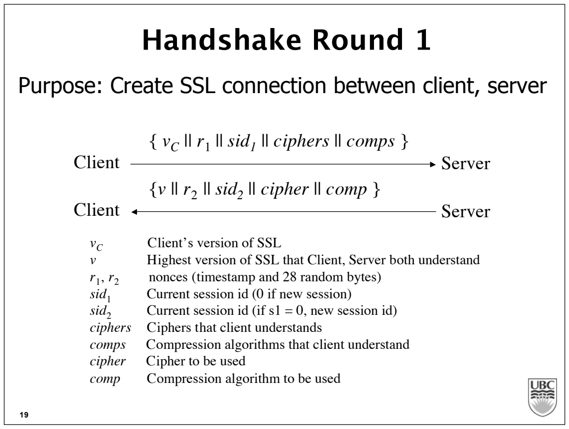

Handshake Round 1

Purpose: Create SSL connection between client, server

$$\text{Client} \xrightarrow{\{\, v_C \parallel r_1 \parallel \mathit{sid}_1 \parallel \mathit{ciphers} \parallel \mathit{comps} \,\}} \text{Server}$$

$$\text{Client} \xleftarrow{\{v \parallel r_2 \parallel \mathit{sid}_2 \parallel \mathit{cipher} \parallel \mathit{comp} \,\}} \text{Server}$$

v_C	Client’s version of SSL
v	Highest version of SSL that Client, Server both understand
r_1, r_2	nonces (timestamp and 28 random bytes)
sid_1	Current session id (0 if new session)
sid_2	Current session id (if s1 = 0, new session id)
ciphers	Ciphers that client understands
comps	Compression algorithms that client understand
cipher	Cipher to be used
comp	Compression algorithm to be used

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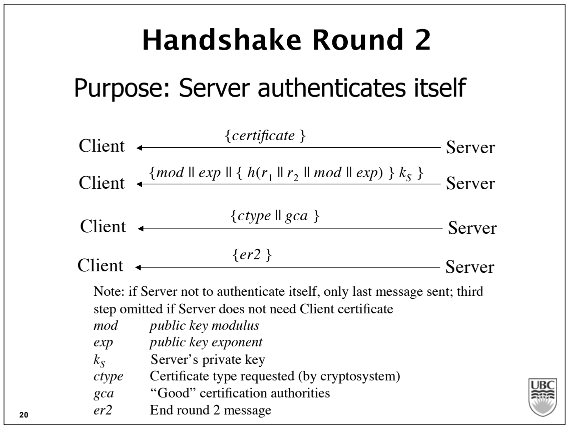

Handshake Round 2

Purpose: Server authenticates itself

$$\text{Client} \xleftarrow{\{\mathit{certificate}\,\}} \text{Server}$$

$$\text{Client} \xleftarrow{\{\mathit{mod} \parallel \mathit{exp} \parallel \{\, h(r_1 \parallel r_2 \parallel \mathit{mod} \parallel \mathit{exp})\,\}\, k_S\,\}} \text{Server}$$

$$\text{Client} \xleftarrow{\{\mathit{ctype} \parallel \mathit{gca}\,\}} \text{Server}$$

$$\text{Client} \xleftarrow{\{\mathit{er2}\,\}} \text{Server}$$

Note: if Server not to authenticate itself, only last message sent; third step omitted if Server does not need Client certificate

mod	*public key modulus*
exp	*public key exponent*
k_S	Server’s private key
ctype	Certificate type requested (by cryptosystem)
gca	“Good” certification authorities
er2	End round 2 message

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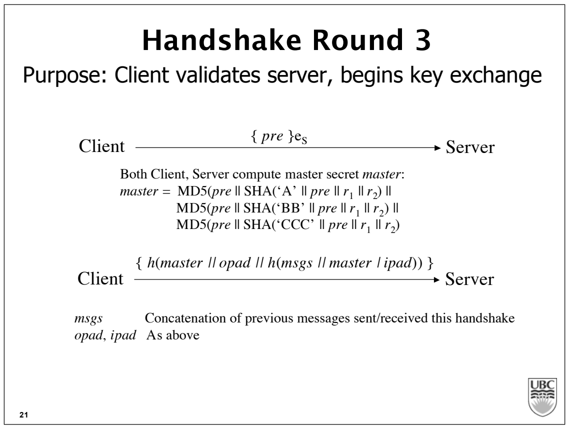

Handshake Round 3

Purpose: Client validates server, begins key exchange

$$\text{Client} \xrightarrow{\{\, \mathit{pre}\,\}\mathrm{e}_S} \text{Server}$$

Both Client, Server compute master secret *master*:

$$\begin{aligned} \mathit{master} = {} & \mathrm{MD5}(\mathit{pre} \parallel \mathrm{SHA}(\text{‘A’} \parallel \mathit{pre} \parallel r_1 \parallel r_2) \parallel \\ & \mathrm{MD5}(\mathit{pre} \parallel \mathrm{SHA}(\text{‘BB’} \parallel \mathit{pre} \parallel r_1 \parallel r_2) \parallel \\ & \mathrm{MD5}(\mathit{pre} \parallel \mathrm{SHA}(\text{‘CCC’} \parallel \mathit{pre} \parallel r_1 \parallel r_2) \end{aligned}$$

$$\text{Client} \xrightarrow{\{\, h(\mathit{master} \,//\, \mathit{opad} \,//\, h(\mathit{msgs} \,//\, \mathit{master} \,/\, \mathit{ipad}))\,\}} \text{Server}$$

msgs	Concatenation of previous messages sent/received this handshake
opad, *ipad*	As above

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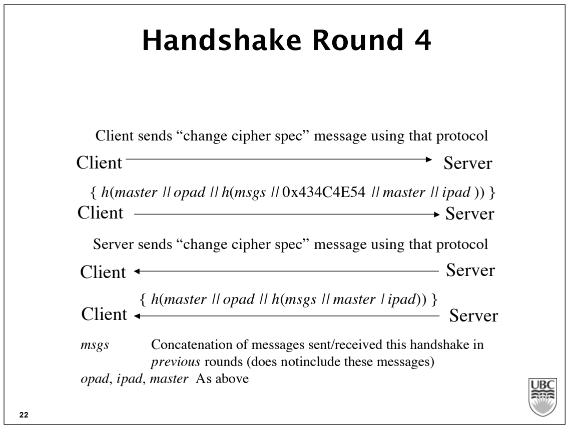

Handshake Round 4

Client sends “change cipher spec” message using that protocol

$$\text{Client} \xrightarrow{\hspace{6em}} \text{Server}$$

$$\text{Client} \xrightarrow{\{\, h(\mathit{master} \,//\, \mathit{opad} \,//\, h(\mathit{msgs} \,//\, \mathrm{0x434C4E54} \,//\, \mathit{master} \,//\, \mathit{ipad}\,))\,\}} \text{Server}$$

Server sends “change cipher spec” message using that protocol

$$\text{Client} \xleftarrow{\hspace{6em}} \text{Server}$$

$$\text{Client} \xleftarrow{\{\, h(\mathit{master} \,//\, \mathit{opad} \,//\, h(\mathit{msgs} \,//\, \mathit{master} \,/\, \mathit{ipad}))\,\}} \text{Server}$$

msgs	Concatenation of messages sent/received this handshake in *previous* rounds (does notinclude these messages)
opad, *ipad*, *master*	As above

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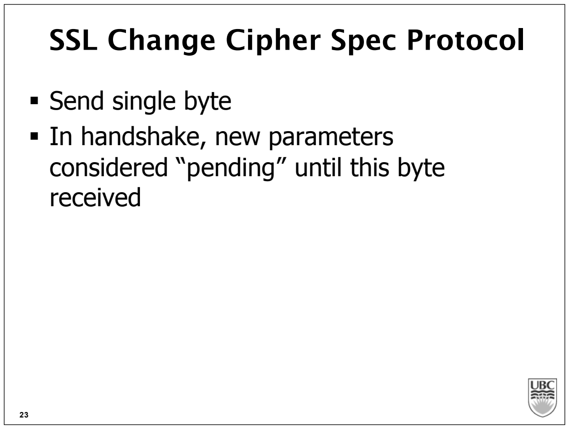

SSL Change Cipher Spec Protocol

- Send single byte
- In handshake, new parameters considered “pending” until this byte received

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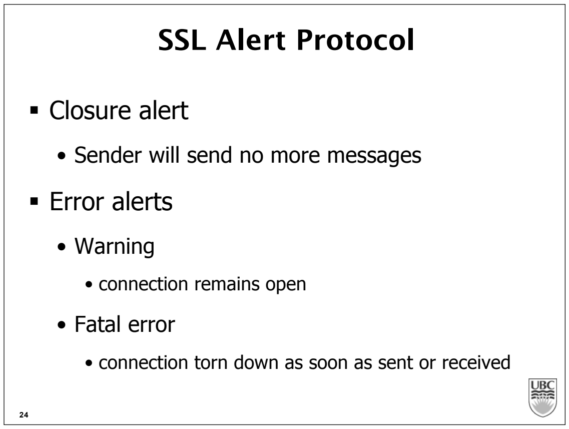

SSL Alert Protocol

- Closure alert
  - Sender will send no more messages
- Error alerts
  - Warning
    - connection remains open
  - Fatal error
    - connection torn down as soon as sent or received

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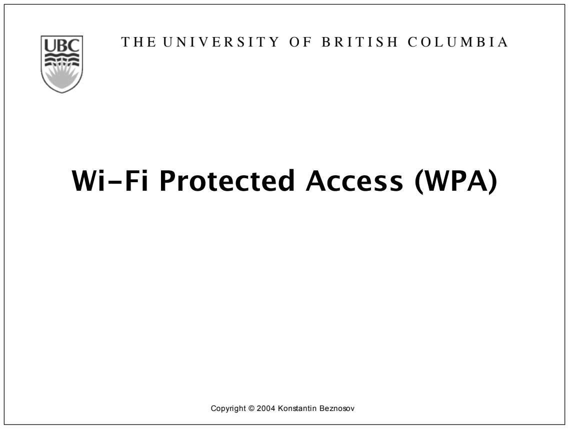

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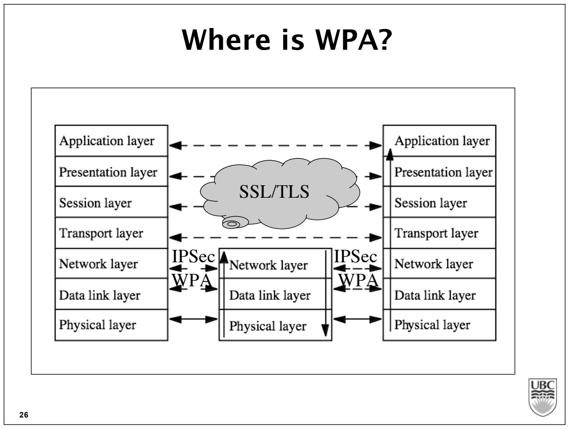
Wi-Fi Protected Access (WPA)



Where is WPA?

Application layer
Presentation layer
Session layer
Transport layer
Network layer
Data link layer
Physical layer

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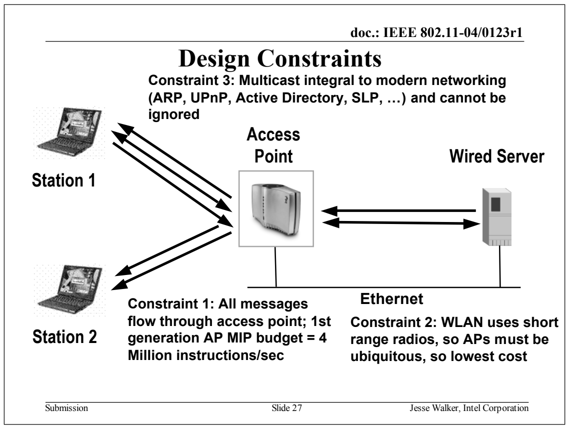


doc.: IEEE 802.11-04/0123r1

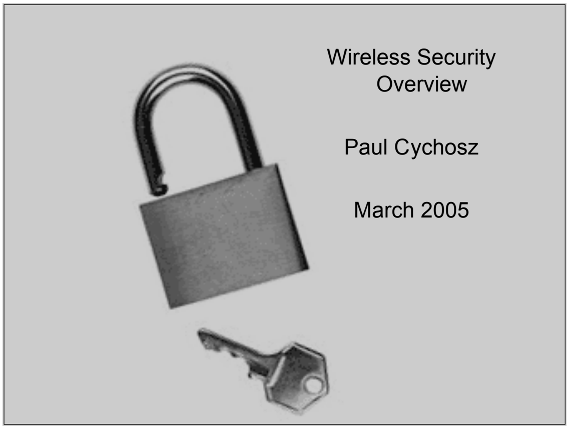
Design Constraints

Constraint 3: Multicast integral to modern networking (ARP, UPnP, Active Directory, SLP, …) and cannot be ignored

Constraint 1: All messages flow through access point; 1st generation AP MIP budget = 4 Million instructions/sec

Constraint 2: WLAN uses short range radios, so APs must be ubiquitous, so lowest cost

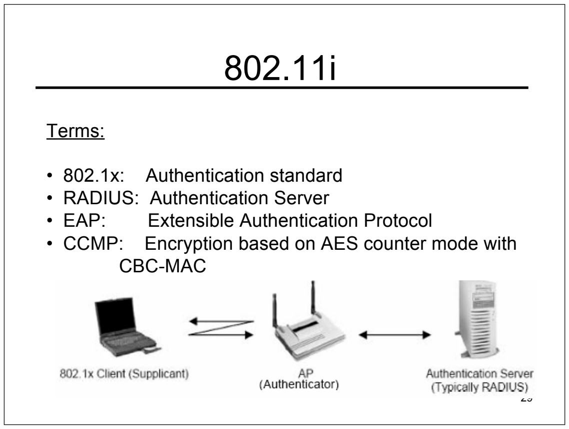
Submission Slide 27 Jesse Walker, Intel Corporation



Wireless Security Overview

Paul Cychosz

March 2005



802.11i

Terms:

- 802.1x: Authentication standard
- RADIUS: Authentication Server
- EAP: Extensible Authentication Protocol
- CCMP: Encryption based on AES counter mode with CBC-MAC

802.1x Client (Supplicant)
AP
(Authenticator)
Authentication Server
(Typically RADIUS)

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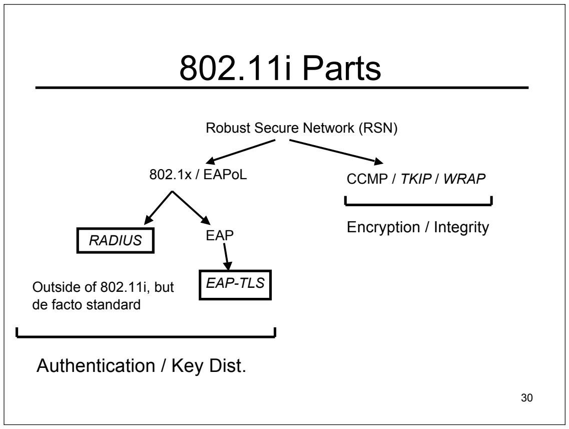

802.11i Parts

Robust Secure Network (RSN)
802.1x / EAPoL
CCMP / *TKIP* / *WRAP*
Encryption / Integrity
RADIUS
EAP
EAP-TLS
Outside of 802.11i, but de facto standard
Authentication / Key Dist.

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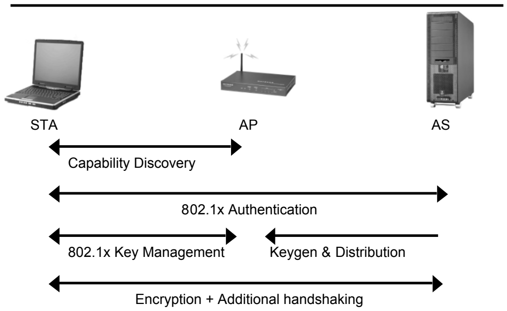
802.11i – First half



STA

AP

AS

Capability Discovery

802.1x Authentication

802.1x Key Management

Keygen & Distribution

Encryption + Additional handshaking

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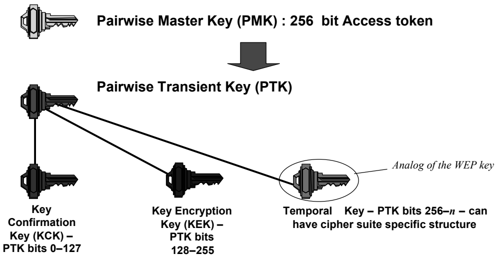
WPA Key Managment

doc.: IEEE 802.11-04/0123r1

802.11i Pairwise Key Hierarchy



Pairwise Master Key (PMK) : 256 bit Access token

Pairwise Transient Key (PTK)

Analog of the WEP key

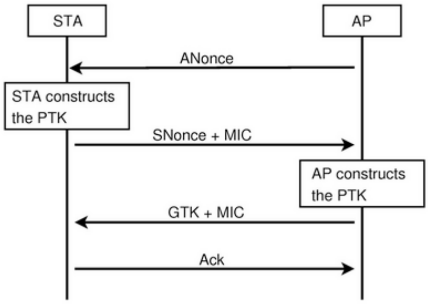
Key Confirmation Key (KCK) – PTK bits 0–127

Key Encryption Key (KEK) – PTK bits 128–255

Temporal Key – PTK bits 256–*n* – can have cipher suite specific structure

Submission Slide 33 Jesse Walker, Intel Corporation

Session Key Establishment



STA

AP

ANonce

STA constructs the PTK

SNonce + MIC

AP constructs the PTK

GTK + MIC

Ack

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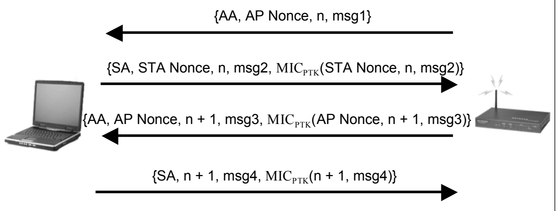
Handshake Details



{AA, AP Nonce, n, msg1}

{SA, STA Nonce, n, msg2, $\mathrm{MIC}_{\mathrm{PTK}}$(STA Nonce, n, msg2)}

{AA, AP Nonce, n + 1, msg3, $\mathrm{MIC}_{\mathrm{PTK}}$(AP Nonce, n + 1, msg3)}

{SA, n + 1, msg4, $\mathrm{MIC}_{\mathrm{PTK}}$(n + 1, msg4)}

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Message 1

- not protected, doesn't matter though

AP → STA: {AA, AP Nonce, n, msg1}

AA: MAC Address of AP

AP Nonce: random value

n: sequence identifier

msg1: PMKID = HMAC-SHA1-128(PMK, "PMK Name" || AA || SPA).

- Client uses AP Nonce and PMK to compute PTK

PTK = 802.11i-PRF(
PMK,
min(AP Nonce, STA Nonce) || max(AP nonce, STA Nonce) ||
min(AP MAC Addr, STA MC Addr) || max(AP MAC Addr, STA MAC Addr))

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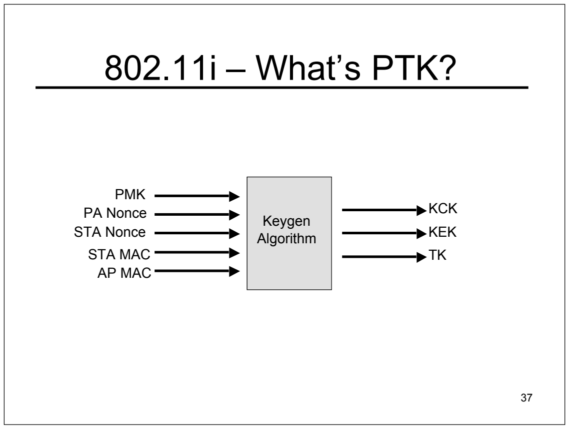

802.11i – What’s PTK?

PMK
PA Nonce
STA Nonce
STA MAC
AP MAC

Keygen Algorithm

KCK
KEK
TK

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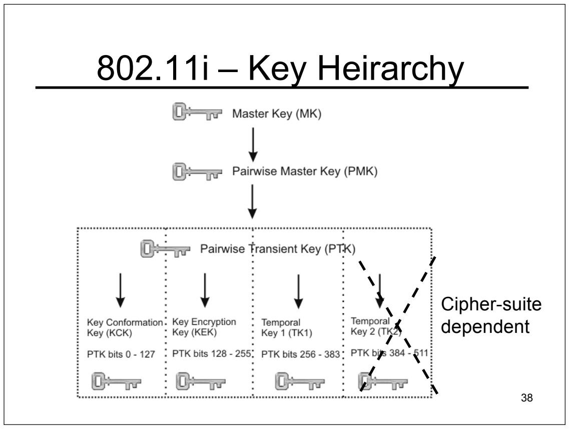

802.11i – Key Heirarchy

Master Key (MK)

Pairwise Master Key (PMK)

Pairwise Transient Key (PTK)

Key Conformation Key (KCK)
PTK bits 0 - 127

Key Encryption Key (KEK)
PTK bits 128 - 255

Temporal Key 1 (TK1)
PTK bits 256 - 383

Temporal Key 2 (TK2)
PTK bits 384 - 511

Cipher-suite dependent

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Message 2

STA → AP: {SA, STA Nonce, n, msg2, MIC_{PTK}(STA Nonce, n, msg2)}

SPA: MAC Address of STA

SNonce: random value

n: sequence identifier, matches msg1

msg2: RSN IE of STA

- AP uses STA Nonce and PMK to compute PTK

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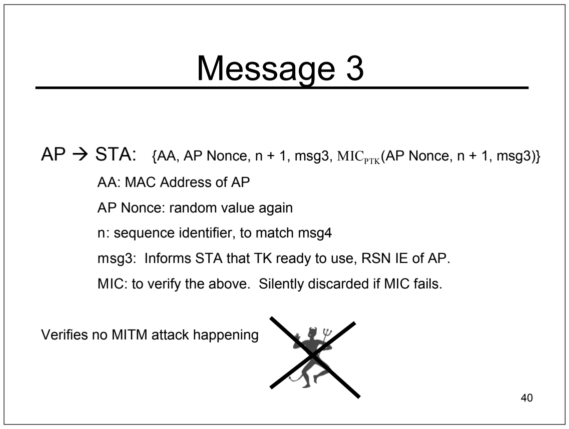

Message 3

AP → STA: {AA, AP Nonce, n + 1, msg3, MIC_{PTK}(AP Nonce, n + 1, msg3)}

AA: MAC Address of AP

AP Nonce: random value again

n: sequence identifier, to match msg4

msg3: Informs STA that TK ready to use, RSN IE of AP.

MIC: to verify the above. Silently discarded if MIC fails.

Verifies no MITM attack happening

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Message 4

STA → AP: {SPA, n + 1, msg4, MIC_{PTK}(n + 1, msg4)}

SPA: MAC Address of STA

n: sequence identifier, to match msg3

MIC: to verify the above. Silently discarded if MIC fails.

- This message dropped in some implementations.
- Only kept for convention

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WPA Data Protection

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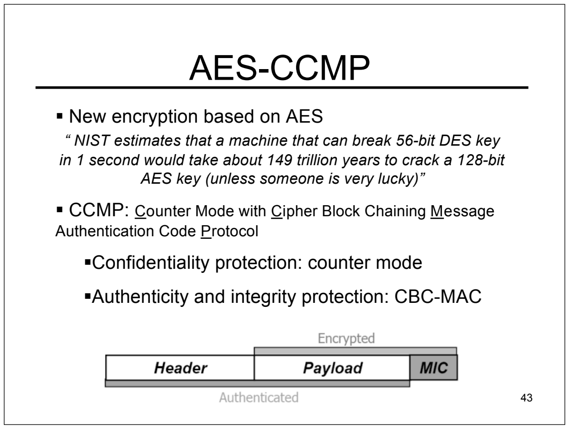

AES-CCMP

- New encryption based on AES

  " NIST estimates that a machine that can break 56-bit DES key in 1 second would take about 149 trillion years to crack a 128-bit AES key (unless someone is very lucky)"

- CCMP: Counter Mode with Cipher Block Chaining Message Authentication Code Protocol
  - Confidentiality protection: counter mode
  - Authenticity and integrity protection: CBC-MAC

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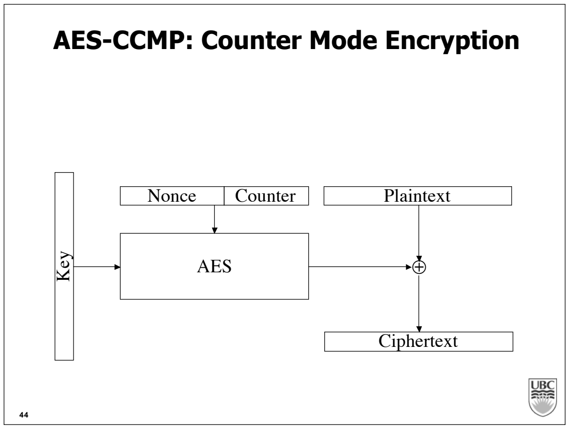

AES-CCMP: Counter Mode Encryption

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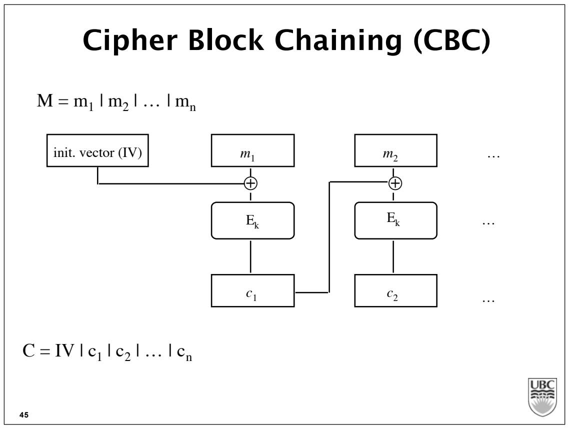

Cipher Block Chaining (CBC)

$M = m_1 \mid m_2 \mid \ldots \mid m_n$

$C = IV \mid c_1 \mid c_2 \mid \ldots \mid c_n$

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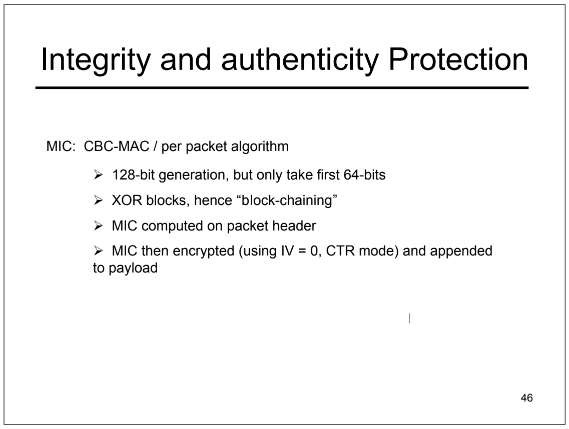

Integrity and authenticity Protection

MIC: CBC-MAC / per packet algorithm

- 128-bit generation, but only take first 64-bits
- XOR blocks, hence "block-chaining"
- MIC computed on packet header
- MIC then encrypted (using IV = 0, CTR mode) and appended to payload

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