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Wireless security (WEP)

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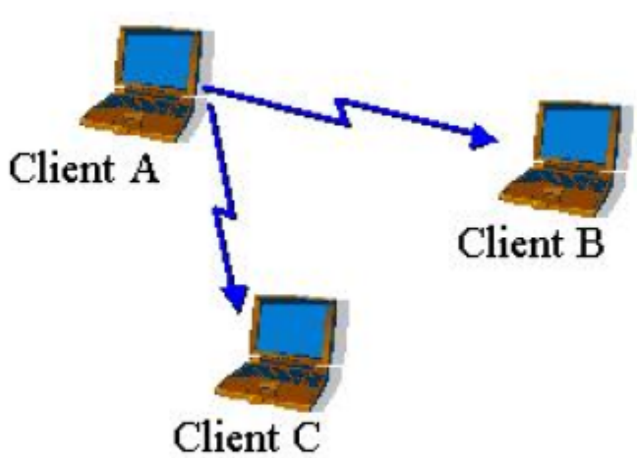
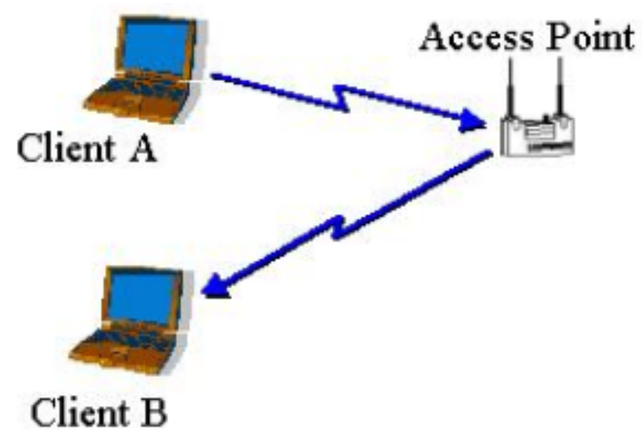
802.11b Overview

- Standard for wireless networks
  - Approved by IEEE in 1999
- Two modes: infrastructure and ad hoc



IBSS (ad hoc) mode
Independent Basic Service Set



BSS (infrastructure) mode
Basic Service Set

Access Point SSID

- Service Set Identifier (SSID) differentiates one access point from another
  - By default, access point broadcasts its SSID in plaintext "beacon frames" every few seconds
- Default SSIDs are easily guessable
  - Linksys defaults to "linksys", Cisco to "tsunami", etc.
  - This gives away the fact that access point is active
- Access point settings can be changed to prevent it from announcing its presence in beacon frames and from using an easily guessable SSID
  - But then every user must know SSID in advance

Wired Equivalent Protocol (WEP)

- Special-purpose protocol for 802.11b
  - Intended to make wireless as secure as wired network
- Goals: confidentiality, integrity, authentication
- Assumes that a secret key is shared between the access point and clients
- Uses RC4 stream cipher seeded with 24-bit initialization vector and 40-bit key
  - Terrible design choice for wireless environment
  - In SSL, we will see how RC4 can be used properly

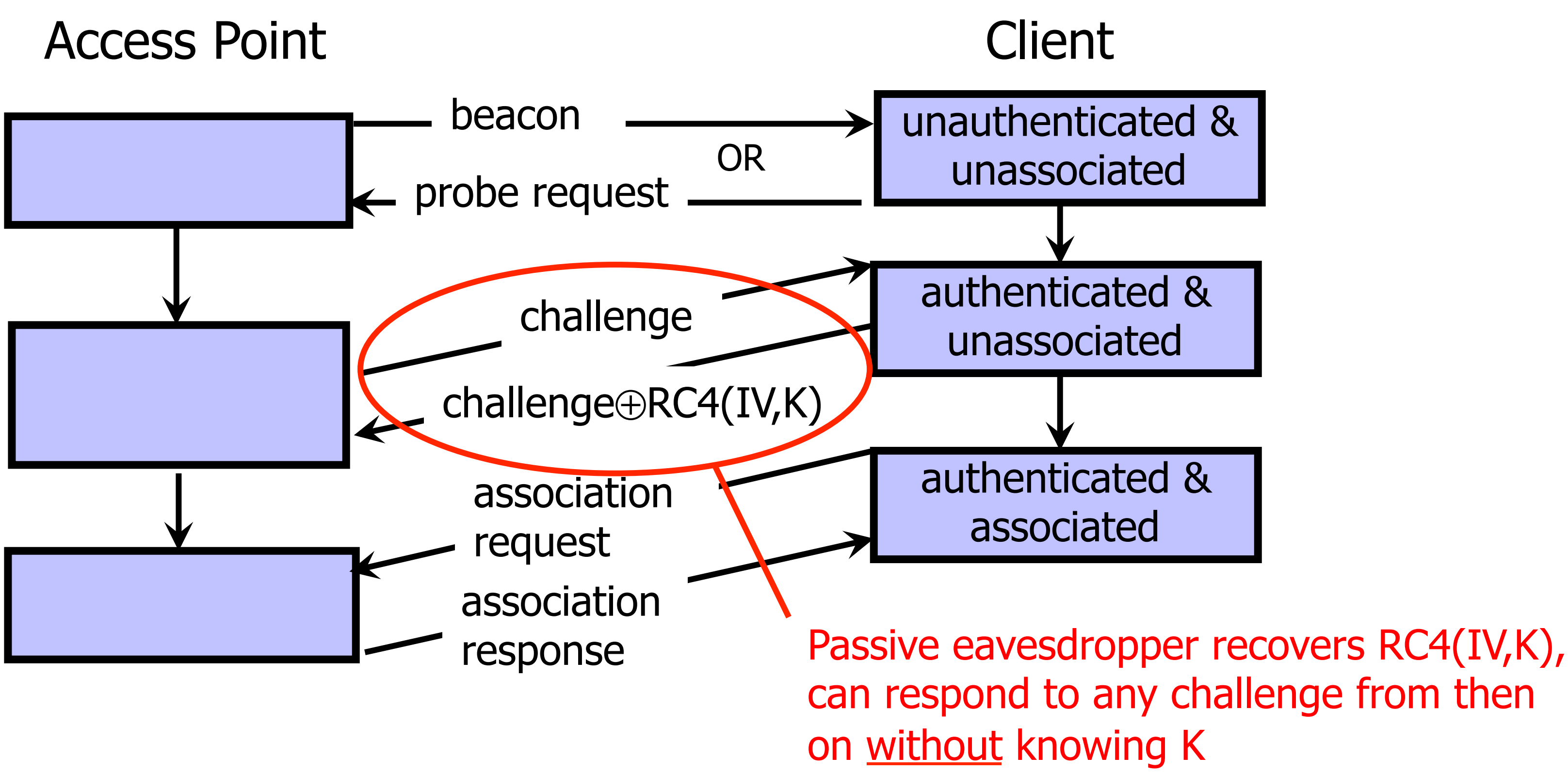
Summary of Attacks

[thanks to N. Borisov]

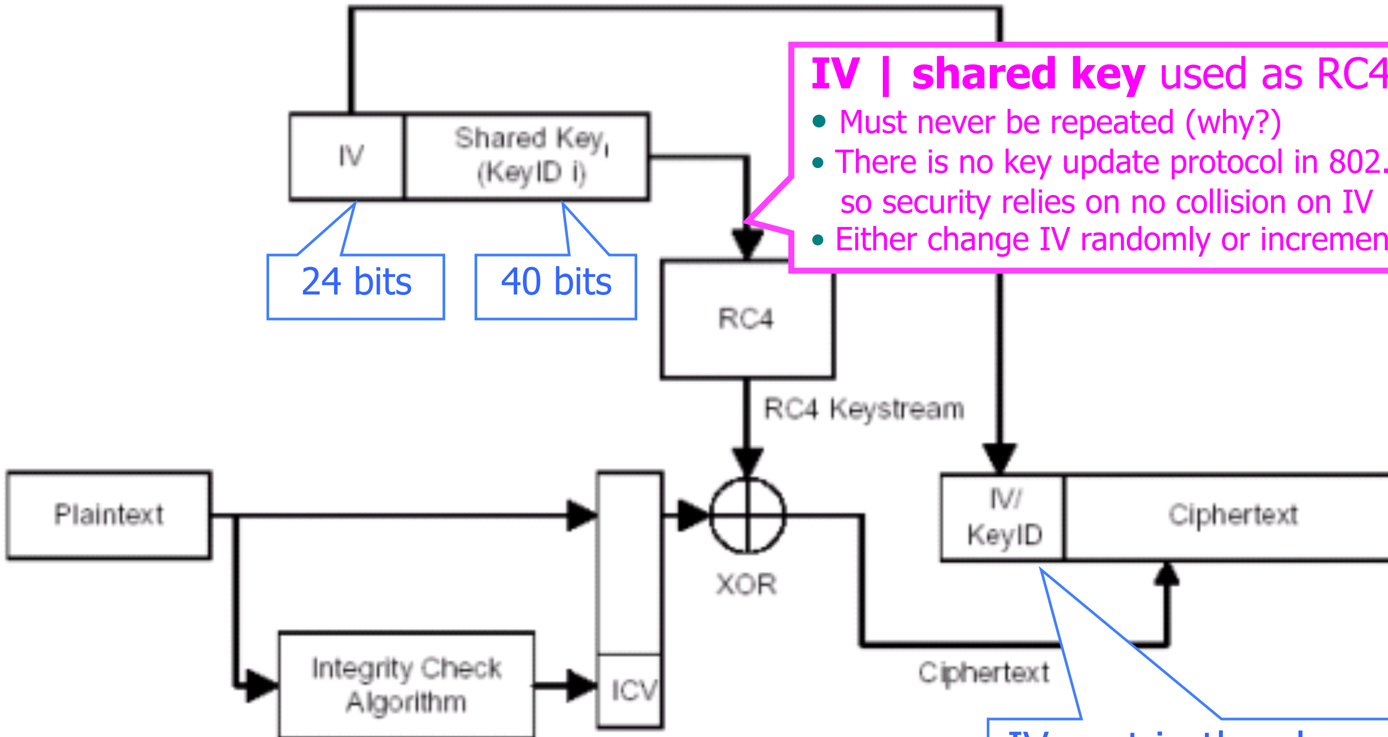
- **None** of security goals are met
- "Insecurity of 802.11" [BGW'01]
  - Keystream reuse [confidentiality]
  - CRC attacks [integrity]
  - Authentication spoofing [access control]
  - IP redirection & TCP reaction attacks [confidentiality]
- "Inductive chosen plaintext attack" [Arb'01]
  - CRC attack [confidentiality]
- "Weaknesses in RC4 key scheduling" [FMS'01]
  - RC4 weakness [confidentiality]

Shared-Key Authentication

Prior to communicating data, access point may require client to authenticate



How WEP Works



24 bits

40 bits

IV | shared key used as RC4 seed

- Must never be repeated (why?)
- There is no key update protocol in 802.11b, so security relies on no collision on IV
- Either change IV randomly or increment

IV sent in the clear

Worse: 802.11b says that **changing IV with each packet is optional!**

CRC-32 checksum is linear in ⊕: if attacker flips some bit in plaintext, there is a known, plaintext-independent set of CRC bits that, if flipped, will produce the same checksum

no integrity!

Why RC4 is a Bad Choice for WEP

- Stream ciphers require synchronization of key streams on both ends of connection
  - This is not suitable when packet losses are common
- WEP solution: a separate seed(IV) for each packet
  - Can decrypt a packet even if a previous packet was lost
- But number of possible seeds is not large enough!
  - RC4 seed = 24-bit initialization vector + fixed key
  - Assuming 1500-byte packets at 11 Mbps, 2^{24} possible IVs will be exhausted in about 5 hours
- Seed reuse is deadly for stream ciphers

Recovering Keystream

- Get access point to encrypt a known plaintext
  - Send spam, access point will encrypt and forward it
  - Get victim to send an email with known content
- If attacker knows plaintext, it is easy to recover keystream from ciphertext
  - $C \oplus M = (M \oplus RC4(IV,key)) \oplus M = RC4(IV,key)$
  - Not a problem if this keystream is not re-used
- Even if attacker doesn't know plaintext, he can exploit regularities (plaintexts are not random)
  - For example, IP packet structure is very regular

Keystream Will Be Re-Used

- In WEP, repeated IV means repeated keystream
- Busy network will repeat IVs often
  - Many cards reset IV to 0 when re-booted, then increment by 1 $\Rightarrow$ expect re-use of low-value IVs
  - If IVs are chosen randomly, expect repetition in $O(2^{12})$ due to birthday paradox (similar to hash collisions)
- Recover keystream for each IV, store in a table
  - (KnownM $\oplus$ RC4(IV,key)) $\oplus$ KnownM = RC4(IV,key)
  - Even if don't know M, can exploit regularities
- Wait for IV to repeat, decrypt and enjoy plaintext
  - (M′ $\oplus$ RC4(IV,key)) $\oplus$ RC4(IV,key) = M′

It Gets Worse

- Misuse of RC4 in WEP is a design flaw with no fix
  - Longer keys do not help!
    - The problem is re-use of IVs, their size is fixed (24 bits)
  - Attacks are passive and very difficult to detect
- Perfect target for Fluhrer et al. attack on RC4
  - Attack requires known IVs of a special form
  - WEP sends IVs in plaintext
  - Generating IVs as counters or random numbers will produce enough "special" IVs in a matter of hours
- This results in key recovery (not just keystream)
  - Can decrypt even ciphertexts whose IV is unique

Fragmentation attack [Bittau, Handley, Lackey `06]

- WEP runs on top of 802.11x
- Fragmentation improves performance in noisy environment
  - 802.11b, 802.11g run on the same bandwidth with cordless phones, microwaves

Keystream retrieval

- Content of first 8 bytes is known in 802.11

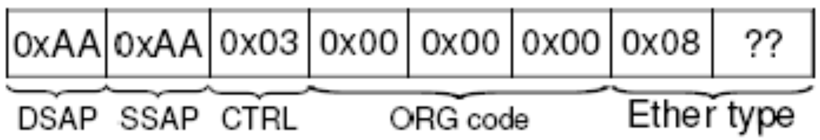


Figure 2. LLC/SNAP header contained in practically all 802.11 data frames.

- The attacker can retrieve 8 bytes of keystrem
  - cleartext ⊕ (cleartext ⊕ RC4(IV, key)) = RC4(IV,key)

Fragment and then encrypt

- 802.11 allows 16 fragmentation
  - the same keystream may be used for 16 times
- The attacker can inject any 64 bytes
  - 64 = 16 fragments * (8– 4 bytes CRC)

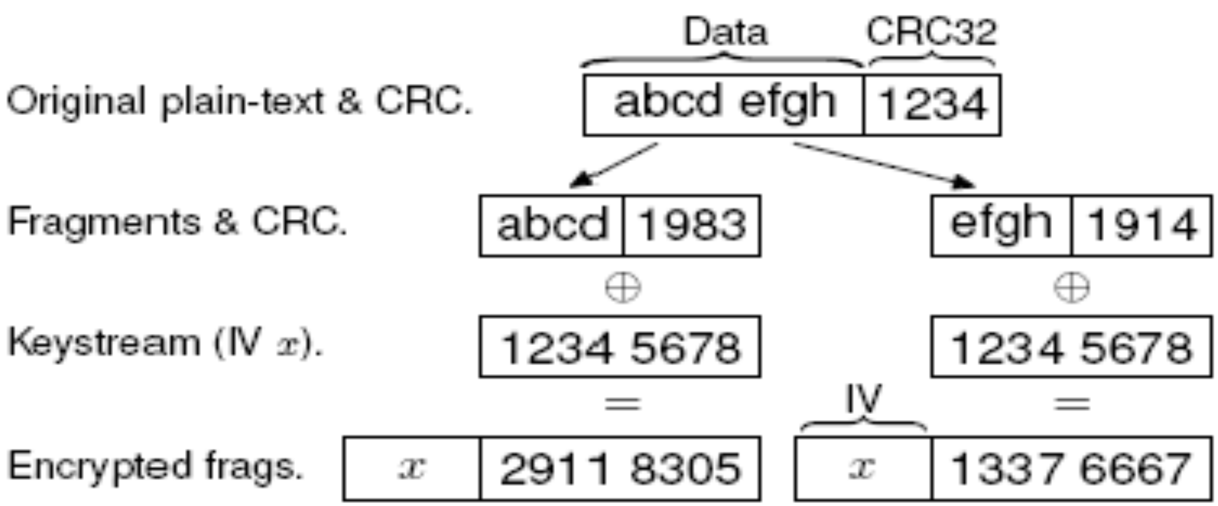


Figure 3. Transmitting a single logical packet in multiple 802.11 fragments.

Decrypt real-time

- Ask AP to forward to a known host
  - WEP only encrypts the packets between clients and AP
  - Attacker pre-pends the packet with the IP address of the known host
  - AP decrypts the packets and forwards the message in clear
- This attack works no matter what the key size is, no matter how often the key changes

Weak Countermeasures

- Run VPN on top of wireless
  - Treat wireless as you would an insecure wired network
  - VPNs have their own security and performance issues
    - Compromise of one client may compromise entire network
- Hide SSID of your access point
  - Still, raw packets will reveal SSID (it is not encrypted!)
- Have each access point maintain a list of network cards addresses that are allowed to connect to it
  - Infeasible for large networks
  - Attacker can sniff a packet from a legitimate card, then re-code (spoof) his card to use a legitimate address

References

- http://tapir.cs.ucl.ac.uk/bittau-wep.pdf
- http://www.aircrack-ng.org/doku.php
- http://www.isaac.cs.berkeley.edu/isaac/wep-faq.html
- http://www.securityfocus.com/infocus/1814