WEP Case Study

Information Assurance

Fall 2009

802.11 or Wi-Fi

- IEEE standard for wireless communication
  - Operates at the physical/data link layer
  - Operates at the 2.4 or 5 GHz radio bands
- Wireless Access Point is the radio base station
  - The access point acts as a gateway to a wired network e.g., ethernet
- Laptop with wireless card uses 802.11 to communicate with the Access Point

External Security Mechanisms

- MAC restrictions at the access point
  - Protects servers from unexpected clients
  - Unacceptable in a dynamic environment
  - No identity integrity. You can reprogram your card to pose as an “accepted” MAC.
  - No confidentiality protection
- IPSec or other VPN tunnel
  - To access point or some IPSec gateway beyond
  - Protects clients from wireless sniffers

Wired Equivalent Privacy (WEP)

- Excellent example of how security system design can go wrong.
  - Flaws widely published in late 2000
  - Unsafe at Any Key Size. Tech. Rep. 00/362 http://www.dis.org/wl/pdf/unsafe.pdf
  - (In)Security of the WEP algorithm. http://www.isaac.cs.berkeley.edu/isaac/wep-faq.html
  - Intercepting Mobile Communications: The Inse
- Took secure elements and put them together poorly

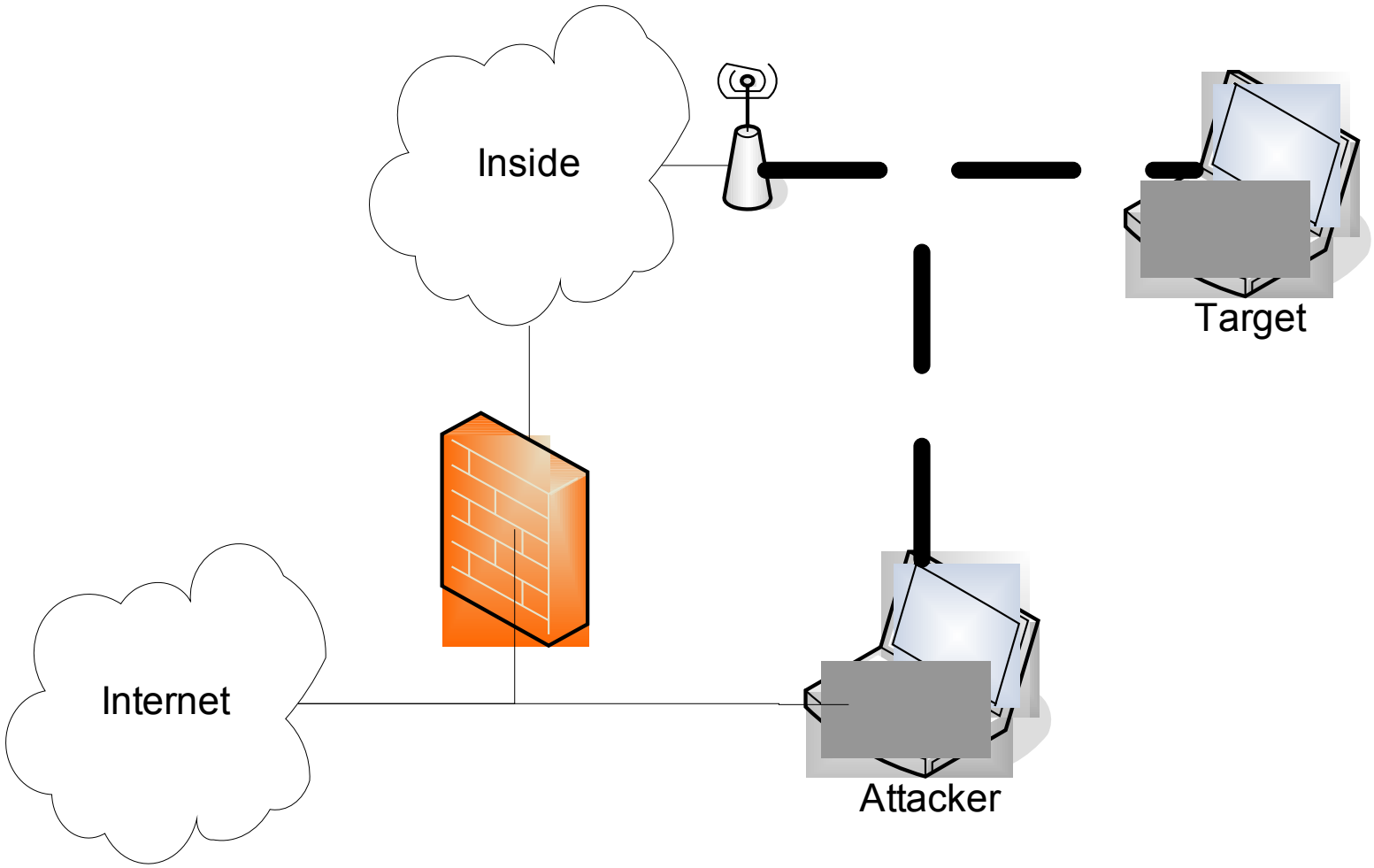
RC4 Stream Cipher

- Takes a key value as input and generates a key stream
  - Key stream is XOR'ed with plaintext to create ciphertext
  - $ci = pi \oplus ki$, for $i = 1, 2, 3$
  - Ciphertext is XOR'ed with key stream to create plaintext,
  - $pi = ci \oplus ki$, for $i = 1, 2, 3$
- Knowing two of key stream, plaintext, and ciphertext lets you easily compute the third
  - Reusing a key value is a really, really bad idea. A well known fact for RC4

Problems reusing a key

- Assume you know two ciphers use the same key
  - C1 = P1 xor K
  - C2 = P2 xor K
  - C1 xor C2 = P1 xor P2 xor K xor K = P1 xor P2
- If you have more Cx using K, get more variations of XOR plaintexts

Key Use Attack Architecture



Key Reuse Active Attacks

- Insert known plaintext
  - Send email (probably forged or annonymized) to someone on the access point and sniff the stream
  - Knowing both plain and ciphertext getting the key stream for that key is just an XOR
- Sniff both the wireless stream and the wire after the access point
  - Correlate the two streams to get plain and ciphertext pairs

Key Reuse Passive Attacks

- Many packets contain well known fields at well known locations
  - E.g. IP header fields
  - Use knowledge about IP headers to get partial key recovery for all packets
- Analyze the plaintext xor's directly
  - Knowing how plaintext streams differ can help in the analysis
  - Use natural language facts to determine the likely plain text

WEP's Key Reuse

- RC4 40 bit seed is created by concatenating a shared secret with a 24 bit initialization vector (IV)
  - Frames can be lost and stream ciphers do not deal with missing bits, so the stream must be reset with each packet.
  - Therefore, a new IV is sent in the clear with each packet
- A family of 2^24 keys for each shared secret
- Keys are cycled for each packet

WEP's Key Reuse

- IV is only 24 bits, the time to repeat IV's (and thus keys) with high probability is very short
  - By birthday paradox, 50% probability of getting some IV reuse after using 4,096 IV's.
  - 99% likely that you get IV re-use after 12,430 frames or 1 or 2 seconds of operation at 11 Mbps.
- Build table of cipher text keyed by IV

No Rekeying

- One key used between an Access Point and all clients
- WEP defines no automatic means of updating the shared key
  - In practice folks do not frequently update WEP keys
  - Ideally should be changing shared key after 6 frames to keep low probability of IV collision (99.999% probability of no IV reuse)

RC4 Weak Keys

- RC4 has weak keys
  - Use of weak keys greatly aid crypto analysis
  - 1 of 256 keys are weak
  - There are standard techniques to avoid the weak keys but WEP does not employee these techniques.
- Airsnort and wepcrack tools leverage weak keys
  - Weakness in the Key Scheduling Algorithm of RC4
    http://www.drizzle.com/%7Eaboba/IEEE/rc4_ksaproc.p

WEP CRC Problems

- We encrypt the CRC, so it is secure, right?
- Wrong. CRC is linear
  - Flipping bits in the ciphertext can be fixed up in the CRC even if the CRC is RC4 encrypted
- This means that an attacker can change the cipher text and fix up the CRC
  - CRC1 xor Delta = CRC2
  - C = CRC1 xor K
  - C xor Delta = C’

Chop Chop Attack

- Interactively decrypt trailing bytes
  - Does not reveal root secret
- Pick off last byte, R
  - Make a guess of R's value and fix up encrypted CRC for shortened packet
  - Access Point will reject packet if guess is wrong
  - Keep guessing until Access Point accepts shortened packet

SSL uses RC4 Safely

- Over a reliable data stream so the 128 bit key does not need to be reset with each packet
- Would need to capture 2^64 streams rather than 2^12 streams to get key reuse with 50% probability
- New keys potentially change all bits not just the bottom 24 bits.
- Rekeying algorithm
- Uses strong crypto hash for MAC
  - HMAC-SHA and HMAC-MD5

IPSec Secures Over Unreliable Protocol

- Uses separate keys in each direction
- Uses 64 bit (for 3DES) or 128 bit (for AES) IV's
- Uses the IV as a salt not as part of the key
- Forces a rekey after at most 2^32 packets
- Uses strong crypto hash for MAC
  - HMAC-SHA and HMAC-MD5

802.11i

- IEEE effort to improve security of the 802.11 spec
  - Using 802.1X for authentication
  - 802.1X is a general L2 protocol
- Wi-Fi Alliance promoting interim standards
  - WPA, a shorter term solution that uses existing hardware
  - WPA2, an implementation of the full 802.11i standard

Wi-Fi Protected Access (WPA)

- Interim solution to run on existing wireless hardware
- Uses Temporal Key Integrity Protocol (TKIP) for data encryption and confidentiality
  - Still uses RC4, 128 bits for encryption
  - Provisions for changing base keys
  - Avoids weak keys
- Includes Michael a Message Integrity Code (MIC)
  - 64 bits
  - Replaces the CRC
  - Observer cannot create new MIC to mask changes to data
- Increases IV from 24 bits to 48
- Mixes the IV and the base key

New Chop Chop TKIP Attack

- Noted on the newsgroup in early November 2008
  - http://dl.aircrack-ng.org/breakingwepandwpa.pd
  - Overview of WEP attacks plus a chop chop attack on TKIP
- Two protections against chop chop
  - If two MIC failures in 60 seconds, assume attack. Shutdown and renegotiate keys after 60 seconds.
  - Out of order packets discarded

TKIP chop chop

- Many installations have multiple QoS Channels.
  - Pick ARP packet from busy QoS Channel
  - Know all bytes of ARP packet except, ICV, MIC, and last byte of address
  - Play on less busy QoS channel to avoid packet ordering problems
- Once you have a good ICV but bad MIC, wait 60 seconds (avoid shutdown)

TKIP Chop Chop Final

- Once you have all values reverse calculate MIC key
  - Now attacker can generate ARP packets directly to clients of interest (whose packet counters are low enough)
  - Could ARP cache poison

WPA2

- Uses AES, specifically Counter-Mode/CBC-MAC Protocol (CCMP)
  - Too computationally intensive in SW for wireless hardware deployed at the time of WEP
- Uses 128 bit key
- Provides data confidentiality by using AES in counter mode
- Provides message authentication using Cipher Block Chaining Message Authentication Code (CBC-MAC)
  - The MAC also covers the packet source and destination

802.11i Summary

	WEP	TKIP	CCMP
Cipher	RC4	RC4	AES
Key Size	40 or 104 bits	128 bits encryption, 64 bit auth	128 bits
Key Life	24-bit IV, wrap	48-bit IV	48-bit IV
Packet Key	Concat.	Mixing Fnc	Not Needed
Integrity			
Data	CRC-32	Michael	CCM
Header	None	Michael	CCM
Replay	None	Use IV	Use IV
Key Mgmt.	None	EAP-based	EAP-based