The Fragmentation Attack in Practice

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September 17, 2005

Aim

Transmit arbitrary WEP data without knowing the key.

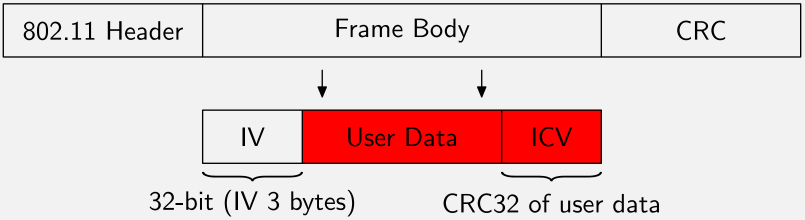
- Only requirement: Eavesdrop a single WEP packet.

Outline

1. Introduction
   - WEP
   - Common Attacks
2. Theory
   - PRGA & WEPWedgie
   - Fragmentation
3. Practice
   - Hardware & Software Limitations
   - Real-life Attack Example
   - Script-kiddie Tool
4. Conclusion

- Bogus implementation of RC4 with a 40-bit shared key.
- Only data portion of data packets is encrypted.
- Initialization Vector (IV) prepended to key on each encryption.
  - IV is transmitted in clear within WEP packets.

Data frame format

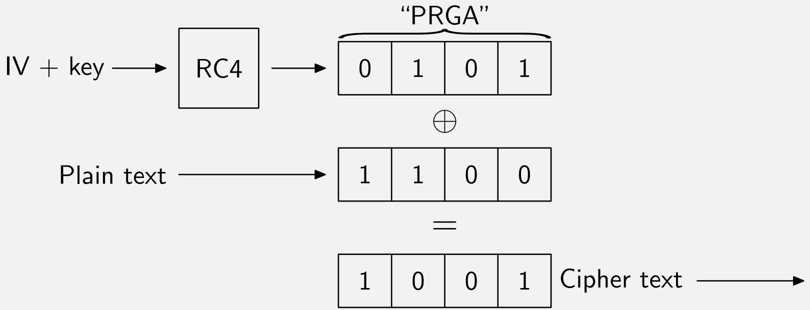


Wired Equivalent Privacy??

Encryption

1. Seed: Choose IV (any 24-bit number) and prepend to key.
2. KSA: Run RC4 Key Scheduling Algorithm on seed.
3. PRGA: Run RC4 Pseudo-Random Generation Algorithm.
4. XOR: XOR user data with PRGA.

WEP Encryption



Common Attacks

1. Bruteforce
   - 40-bit key!
   - ASCII Passphrase.
     - Microsoft Windows XP requires *exactly* 5 or 13 characters.
2. KSA
   - The weak IV attack (aka FMS).
   - Requires ≈ 300,000–3,000,000 unique IVs.
     - Many networks don't have much traffic.
     - 13% probability IVs improve the attack a lot.
     - aircrack is a good implementation.
3. PRGA
   - WEP-wedgie: Shared key authentication networks.
   - PRGA discovery: Bit-flipping, IV collisions, etc.
   - Fragmentation: Not (yet) public!

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PRGA

If we had PRGA for an IV:

- Decrypt all packets which use that IV (cipher text ⊕ PRGA).
  - With PRGAs for different IVs, we can decrypt more packets (IV dictionary).
- Encrypt user data with that IV (data ⊕ PRGA).
  - Can always use same IV.

Sample PRGA

0	1	0	1	PRGA
0	0	1	1	Plain text
0	1	1	0	Cipher text

If we intercept cipher text and somehow know the clear text:

- Discover PRGA for that IV (cipher text ⊕ clear text).

PRGA

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1. Access point (AP) sends 128 byte challenge.
2. Client replies with encrypted version of challenge.

WEP-wedgie

Greets to Anton

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Have 128 bytes of PRGA!

(challenge $\oplus$ encrypted challenge) reveals PRGA for IV client used.

- Can encrypt $128 - 4$ (ICV) arbitrary bytes of data.
- Can decrypt first 128 bytes of packets which use that IV.

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Optimization

Force clients to disconnect by spoofing de-authentication requests—management frames not encrypted!

All data is *Logical Link Control* (LLC) encapsulated.

- Commonly (always) followed by SNAP.
  - Most likely followed by IP.
  - At times followed by ARP.

LLC/SNAP header for IP packet

0xAA	0xAA	0x03	0x00	0x00	0x00	0x08	0x00
DSAP	SSAP	CTRL	ORG code			Ether type	

ARP packets have 0x0806 as ethernet type!

- Distinguishable by fixed and short length.

In general, we can recover at least 8 bytes of PRGA.

Fragmentation

Greets: Josh Lackey, h1kari, anton, abaddon

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Some details:

- Each fragment needs ICV. Only $8 - 4 = 4$ bytes for real data.
- Fragment No. field is 4 bits. Only 16 fragments possible.
  - Max data length $= 2^4 \times 4 = 64$.
  - Can use IP fragmentation too.
- Can generate traffic for which response is known, revealing more PRGA.

Outline of Attack

1. Eavesdrop a WEP packet.
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Hardware

Prism2 (Intersil) based cards.

- Host-AP mode. Can send (almost) raw 802.11 frames.
- Monitor mode. Firmware passes all frames to kernel.

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Re-write the fields via debug port! (greets to h1kari)

1. Queue the packet on the card for TX via the normal interface.
2. Locate the packet on the card's memory via AUX port.
3. Instruct the card to begin TX.
4. After the firmware processed the header, but before it is sent, overwrite it.
    - In practice, we always win the race!

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1. Queue and locate packet with 2 random bytes in MAC addr.
2. Busy wait reading duration until it changes.
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0x08	0x00	0x00	0x00	0x00	0xDE	0xFA	0xCE	0xD0	0x00
Frame CTRL		Duration		Address 1					

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- Able to send any 802.11 frame and receive all frames.

- Eavesdrop WEP packet and determine 8 bytes of PRGA.
- Transmit ARP request (36 bytes) in 9 fragments of 4 data bytes.
  - Who has 192.168.0.1 tell 192.168.0.123.
- Didn't get any reply.
  - Wrong IP network.
  - But AP relayed the packet (since it's a broadcast).
  - Re-encrypted by the AP.
  - Knowing the contents, we discover 36 bytes of PRGA.
- Send ARP request padded with x 0s (in larger fragments).
  - AP relays the longer ARP request.
  - Discover $36 + x$ bytes of PRGA.
  - Repeat until, say, 1504 bytes of PRGA are known.
- Can send 1500 bytes of data *without* fragmenting.

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PRGA determination

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  - No luck—need to be smarter.
- Eavesdrop ARP request/reply and try to decrypt it.
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ARP decryption

Know whether its ARP request/reply depending on whether its a broadcast or not.

LLC/SNAP	ARP header	Src MAC	??	??	??	??

Src IP

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ARP decryption

Know source MAC—transmitted in clear in 802.11 header!

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ARP decryption

Guess first IP byte: 192. Calculate PRGA and send data with it. If it's relayed, we are correct.

LLC/SNAP	ARP header	Src MAC	192	??	??	??

Src IP

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ARP decryption

Guess second IP byte: 168.

LLC/SNAP	ARP header	Src MAC	192	168	??	??
			Src IP			

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ARP decryption

Guess third IP byte: 1.

LLC/SNAP	ARP header	Src MAC	192	168	01	??

Src IP

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ARP decryption

Obtain third IP byte (after at most 256 tries): 11.

LLC/SNAP	ARP header	Src MAC	192	168	11	??

$$\underbrace{192 \quad 168 \quad 11 \quad ??}_{\text{Src IP}}$$

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ARP decryption

Send ARP who has 192.168.11.1 tell 192.168.11.123.

- Got reply! IP network is 192.168.11.0.

LLC/SNAP	ARP header	Src MAC	192	168	11	??

Src IP

By sending ARP request for 192.168.11.1

- Know MAC of router (clear in 802.11 header).
- Router knows our MAC/IP pair (ARP backward learning).

Send ICMP echo to a host we own on Internet.

- Use "our" source MAC/IP pair.
- Use router MAC as destination.
- Obtain network's public IP address from Internet box.

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Generate traffic to speed up KSA attacks

- Cause controlled host on Internet to flood network.
- Send ARP requests and ICMPs to broadcast IP.
  - Could generate $\approx$ 200 packets/s of traffic.
- Key was actually 40-bit alpha-numeric ASCII.
  - Bruteforcable in $\leq$ 5 minutes ...

Login to AP and clean up

- Default passwords work great. (root without password here.)
- Clear the logs.
  - Obtain ISP login and send e-mail to customer advising him to use a VPN. [password is recoverable too ...]

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The Tool: `wesside`

Hardware

Designed for Atheros based cards.

- Queue the packet and it shall be sent—No firmware hacks!
- Supports 802.11 a/b/g.
- FreeBSD `ath` driver patched to support injection.
  - Problem with sending 802.11 ACKs. Possibly they are sent too late—DIFS rather than SIFS.
  - Work around: Have another card in range with the same MAC as the attacker. The card will respond to data with ACKs.

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3. Upon capturing an ARP request it discovers the network IP. Sends 256 PRGA guesses in parallel to different multicast addresses. Correct guess is in address of relayed packet.
4. Obtains router's MAC by ARP request to ".1" IP.
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IV dictionary built in parallel!

Binds to a TAP interface allowing transmission and reception (if PRGA is known).

After a single ARP request is eavesdropped:

- 144 bytes of PRGA are recovered in 1 second.
- IP is decrypted in < 30 seconds.
- Internet host is contacted in < 1 minute (total time).

The Tool: `wesside`
Bootstrap time & flood rate

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Traffic generation rate

Flood source	$\approx$ p/s
802.11b client FTP download.	150
LAN client `ping -f` (no replies).	550
Internet flood (MTU sized packets).	250
ARP replay.	350
Internet flood (short packets).	950

Full dictionary requires $\approx \frac{2^{24}}{250} \times \frac{1}{3600} \approx 18.6$ hours of flooding.

Total attack time for /dev/urandom keys

Key	Packets	Time (m)
2C:CE:FC:1D:2B	100,000	1.93
80:19:B8:3F:C8	200,000	3.83
6F:34:11:BC:A3	200,000	4.30
91:B7:C0:A7:F7	300,000	5.45
3B:07:DA:02:B7	300,000	5.60
EB:A6:50:D0:2B:DA:CC:B7:E1:B7:E8:50:59	1,700,000	30.77
D9:06:CA:9E:EA:B3:18:CD:24:9F:2E:5E:10	2,400,000	42.85
5E:02:F4:83:FE:F6:27:10:21:EC:8E:87:27	2,700,000	49.17
64:AC:EE:55:B7:7E:27:93:09:6B:78:00:78	9,000,000	156.58
41:0A:68:52:5B:BE:C7:64:D7:09:FC:CC:BB	10,000,000	181.28

The Tool: wesside

Screen shot

```
# ./wesside -s 1.2.3.4
[10:49:50] Setting up ath0... done
[10:49:50] Opened tap device: tap3
[10:49:50] Set tap MAC to: 00:00:DE:FA:CE:0D
[10:49:50] Looking for a victim...
[10:49:53] Found SSID(sorbo) BSS=(00:06:25:FF:D2:29) chan=11
[10:49:53] Authenticated
[10:49:53] Associated (ID=3)
...
```

```
...
[10:49:54] Got ARP request from (08:00:46:9E:AF:CD)
[10:49:54] Got 8 bytes of prga IV=(42:bc:00)
[10:49:54] Got 36 bytes of prga IV=(43:bc:00)
[10:49:55] Got 144 bytes of prga IV=(52:bc:00)
[10:49:58] Guessing PRGA 5f (IP byte=255)
[10:49:58] Got clear-text byte: 192
[10:50:00] Guessing PRGA 2d (IP byte=175)
[10:50:00] Got clear-text byte: 168
[10:50:09] Guessing PRGA f7 (IP byte=0)
[10:50:09] Got clear-text byte: 1
[10:50:18] Guessing PRGA f7 (IP byte=102)
[10:50:18] Got clear-text byte: 100
[10:50:18] Got IP=(192.168.1.100)
[10:50:18] My IP=(192.168.1.123)
[10:50:18] Sending arp request for: 192.168.1.1
[10:50:18] Got arp reply from (00:06:25:FF:D2:27)
...
```

```
...
[10:49:54] Got ARP request from (08:00:46:9E:AF:CD)
[10:49:54] Got 8 bytes of prga IV=(42:bc:00)
[10:49:54] Got 36 bytes of prga IV=(43:bc:00)
[10:49:55] Got 144 bytes of prga IV=(52:bc:00)
[10:49:58] Guessing PRGA 5f (IP byte=255)
[10:49:58] Got clear-text byte: 192
[10:50:00] Guessing PRGA 2d (IP byte=175)
[10:50:00] Got clear-text byte: 168
[10:50:09] Guessing PRGA f7 (IP byte=0)
[10:50:09] Got clear-text byte: 1
[10:50:18] Guessing PRGA f7 (IP byte=102)
[10:50:18] Got clear-text byte: 100
[10:50:18] Got IP=(192.168.1.100)
[10:50:18] My IP=(192.168.1.123)
[10:50:18] Sending arp request for: 192.168.1.1
[10:50:18] Got arp reply from (00:06:25:FF:D2:27)
...
```

```
...
[10:51:28] WEP=000100460 (next crack at 100000) (rate=1448)
[10:51:28] Starting crack PID=17410
[10:52:28] WEP=000185271 (next crack at 200000) (rate=1426)
[10:52:28] Stopping crack PID=17410
[10:52:39] WEP=000201124 (next crack at 200000) (rate=1433)
[10:52:39] Starting crack PID=17412
[10:52:40] WEP=000203778 (next crack at 300000) (rate=1365)

[10:52:41] KEY=(2C:CE:FC:1D:2B)
Owned in 2.85 minutes
#
```

Conclusion and Future Work

- Able to transmit arbitrary data on most (all?) 802.11 WEP networks after having eavesdropped a single data packet.
- Can potentially recover a WEP key in a couple of hours.

Future Work:

- Develop method for higher flood rates (p/s).
- Study how IV generator can be reset—smaller dictionaries.
- Implement a more sophisticated tool and make a Live CD!

A final thought for the adventurous. . .

Assume the AP uses default password for WWW interface.

- Connect to WWW and request WEP configuration page.
- Decrypt TCP sequence number for connection ACK.
- Decrypt contents of page returned—may contain WEP key!