BEAST: A Surprising Crypto Attack Against HTTPS

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B.E.A.S.T

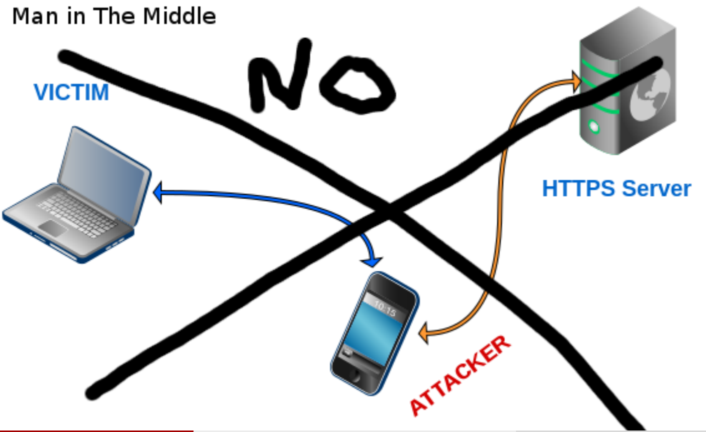
- B.E.A.S.T: Browser Exploit Against SSL/TLS
- A new way to exploit a decade-old known vulnerability in SSL/TLS.
- The attack combines crypto and browser security weaknesses.
- Demo: BEAST decrypts HTTPS requests and obtains secret cookies.

HTTPS:// **S**ecure HTTP

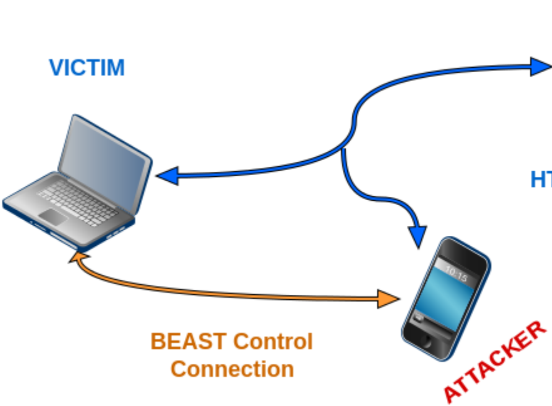
- HTTP over an encrypted SSL/TLS connection provides
  - **Confidentiality** (Encryption)
  - Integrity (Message Authentication Code)
  - Authenticity (Certificates)

NOT a MiTM attack

- Attack against the confidentiality
- Encrypted data is not modified
- No certificates were harmed



B.E.A.S.T in the network



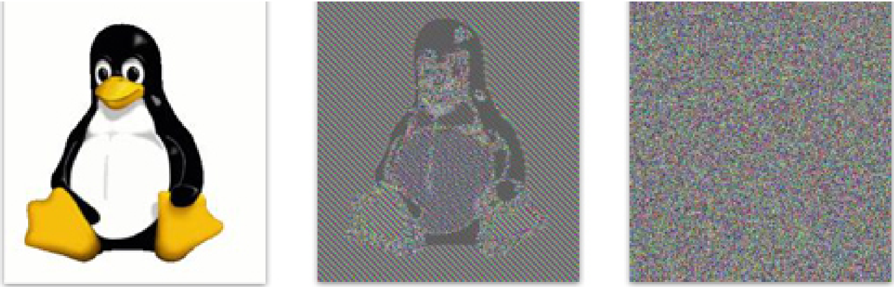
Encryption in SSL/TLS

- Unique symmetric encryption keys negotiated by handshake
- Block ciphers in CBC mode (3DES,AES)
- Stream ciphers (RC4)

Block Ciphers

- Operate on fixed-length groups of bits (64,128,256)
- One secret key and two algorithms (E_k,D_k)
- Messages are padded and broken into blocks

Cipher Block Chaining (CBC)



ORIGINAL IMAGE | ENCRYPTED USING ECB - MODE | ENCRYPTED USING CBC - MODE

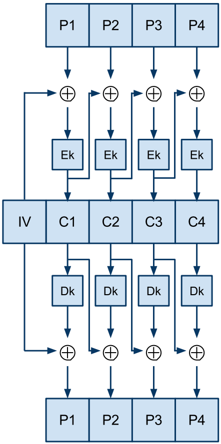
Cipher Block Chaining (CBC)

- Encrypt:

$$C_i = E_k(C_{i-1} \oplus P_i)$$
$$C_0 = \text{IV}$$

- Decrypt:

$$C_0 = \text{IV}$$
$$P_i = D_k(C_i) \oplus C_{i-1}$$



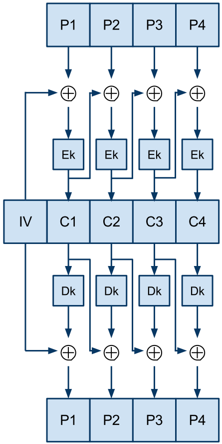
CBC Initialization Vector (IV)

- Same input (key and plaintext) but different IV = different output
- IV need NOT be secret
- IV MUST be unpredictable before attackers can chose plaintext

Dai's Attack against CBC (1)

- Two assumptions:
  - Adversary can choose P_i.
  - Adversary can see C_i.
- Idea: use P_4 to make a guess for previous plaintext blocks. Suppose he suspects that P_1 is X, he then sets $P_4 := C_3 \oplus C_0 \oplus X$.
- If P_1 is X, then:

$$\begin{aligned} C_4 &= E_k(C_3 \oplus P_4) \\ &= E_k(C_3 \oplus C_3 \oplus C_0 \oplus X) \\ &= E_k(C_0 \oplus P_1) \\ &= C_1. \end{aligned}$$



Dai's Attack against CBC (2)

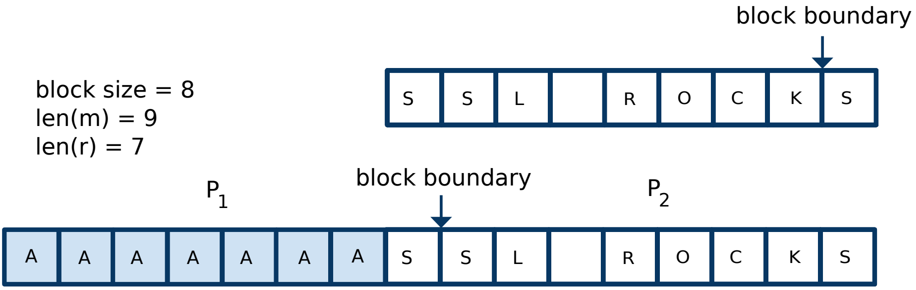
- If P_1 takes W possible values, it can be decrypted after at most W guesses.
- In practice, W is often too large (2^{128}).
- How to make W small?

How to make it practical?

How!?

Chosen-Boundary Attack against CBC

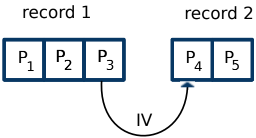
- Idea: move block boundaries around to shrink W to 256.
- Assumption: the adversary can prepend some bytes to the plaintext.



Application: Decrypting HTTPS requests (1)

HTTPS Overview

- HTTP over SSL. Used to protect cookies in requests, and responses.
- SSL receives the HTTP message from the Application Layer as raw data, which is then fragmented into records of length less than or equal to 2^{14} bytes.
- Vulnerability: each record is encrypted in CBC mode with chained IVs; i.e., the CBC IV for each record except the first is the previous records' last ciphertext block.

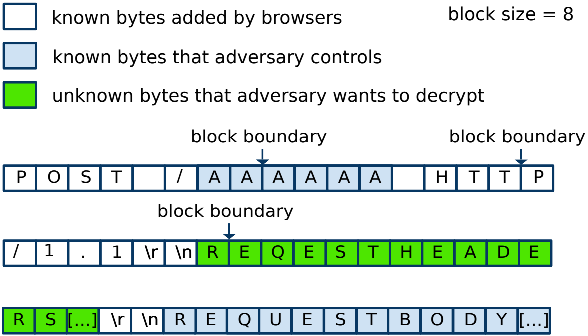


Application: Decrypting HTTPS requests (2)

Threat Model

- Alice visits https://bob.com.
- Alice visits http://mallory.com operated by Mallory.
- Mallory can sniff to see network traffic from Alice to https://bob.com.

Application: Decrypting HTTPS requests



- Java Applet URLConnection API: confirmed.
- HTML5 WebSocket API: confirmed.
- SilverLight WebClient API: unconfirmed, doesn't work with the obvious API
- XHTMLRequest: could be possible, we didn't have luck
- Flash: poor Flash!, too many problems already, please leave him alone!

DEMO

DEMO

A Brief History of The Attack

- 1995: P. Rogaway observed that CBC mode is not secure against chosen-plaintext attack if the IV is predictable.
- 1996: SSL 3.0 was born, IV is predictable.
- 1999: TLS 1.0 was born, IV is predictable.
- 2002: W. Dai then Bellare et al. extended Rogaways attack to SSH. B. Moller then realized that Dais attack can also be used against SSL. A workaround was implemented in OpenSSL.
- 2004 and 2006: G. Bard tried the attack to SSL in web browsers. Bards work has been largely ignored, since his attacks dont really work.
- 2006: TLS 1.1 was born, IV is unpredictable.
- 2010: Predictable IV was alleged as the backdoor in OpenBSDs IPSEC implementation.
- 2011: BEAST: Chosen-boundary attack was invented.

(Broken) Countermeasures (1)

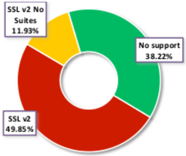
TLS 1.1 and TLS 1.2

- Not enough good TLS servers: just over 3000 servers supporting TLS 1.1 or higher.
- Counter-countermeasure: drop browsers' TLS ClientHello.

Half of all trusted servers support the insecure SSL v2 protocol

- Modern browsers won't use it, but wide support for SSL v2 demonstrates how we neglect to give any attention to SSL configuration
- Virtually all servers support SSLv3 and TLS v1.0
- Virtually no support for TLS v1.1 (released in 2006) or TLS v1.2 (released in 2008)
- At least 10,462 servers will accept SSLv2 but only deliver a user-friendly error message over HTTP

BLACK HAT USA 2010 QUALYS



Protocol	Support	Best protocol
SSL v2.0	302,886	-
SSL v3.0	607,249	3,249
TLS v1.0	604,242	603,404
TLS v1.1	838	827
TLS v1.2	11	11

(Broken) Countermeasures (2)

Stream Cipher (RC4)

- RC4 is not FIPS-approved encryption
- Counter-countermeasure: Google's SSL optimization False Start.

(Broken) Countermeasures (3)

Compression

- Counter-countermeasure: Google's SSL optimization False Start.

(Broken) Countermeasures (4)

OpenSSL's fix

- Idea: preventing the attacker from controlling next plaintext block.
- Prepend an empty record to each message (OpenSSL 0.9.6d, May 2002)
- Compatibility issues, turned off by default in most products

(Broken) Countermeasures (5)

Oracle's proposal

- Same idea as OpenSSL.
- Let's break each message into two records: the first record contains the first byte of the message, and the second record contains the rest.
- Some compatibility issues with applications: ssl_read()="G"

What's next?

- Is it possible to decrypt HTTPS responses?
- More SSL applications: SSL VPN, Instant Messaging, etc.

Conclusion

- Crypto is hard let's go party!
- Questions?