Computer Security Capstone

Project I: IPsec Session Hijacking

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Goals

- Understand how to hijack IPsec sessions

- You will learn about
  - Sniffing IPv4/ESP/TCP packets
  - Dumping the key to generate HMAC signature
  - Fabricating IPv4/ESP/TCP packets

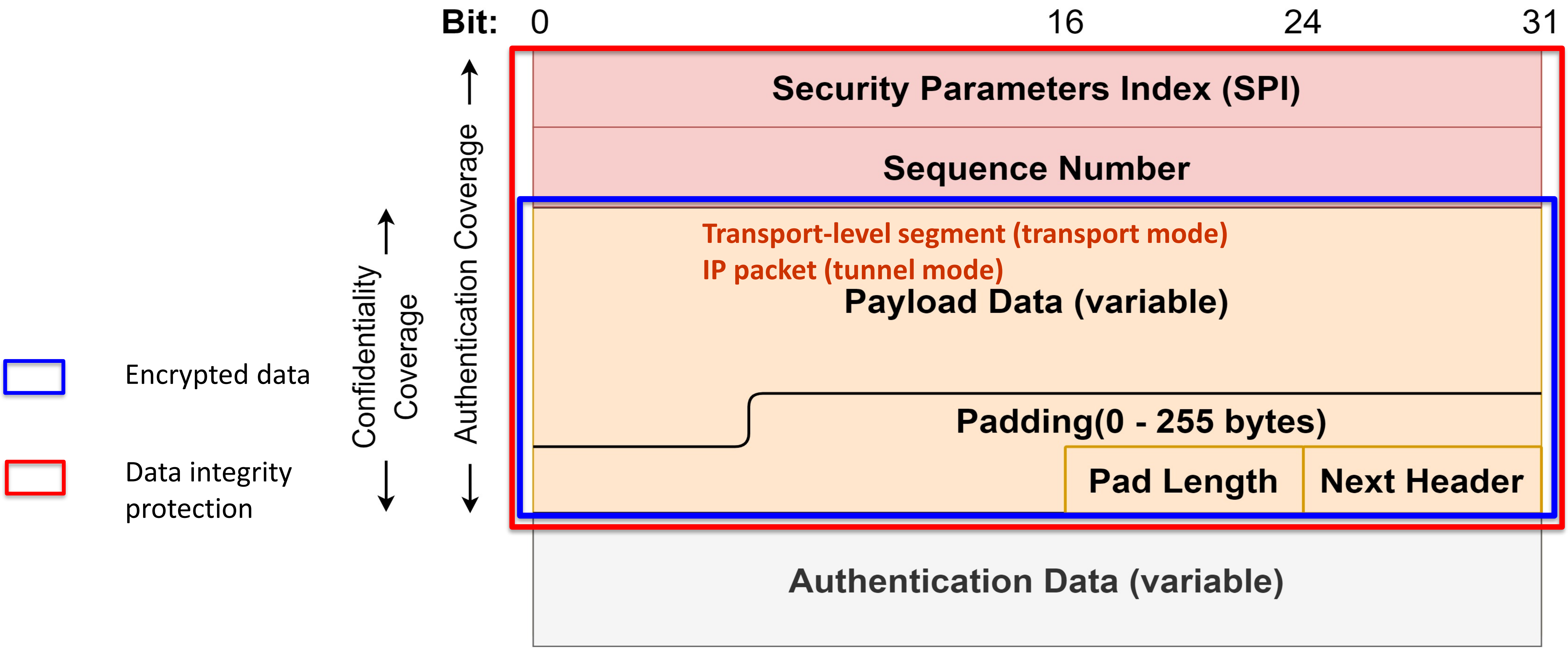
What is IPsec?

- Internet Protocol Security (IPsec) is a secure network protocol suite
  - It provides secure communication by authenticating and encrypting data
  - It ensures the confidentiality and integrity of the data
- Two main protocols
  - Internet Key Exchange (IKE): Used for negotiation and establishment of security associations (SAs)
  - Encapsulating Security Payload (ESP): Provides confidentiality, integrity, authentication

IPsec Primer: Security Associations

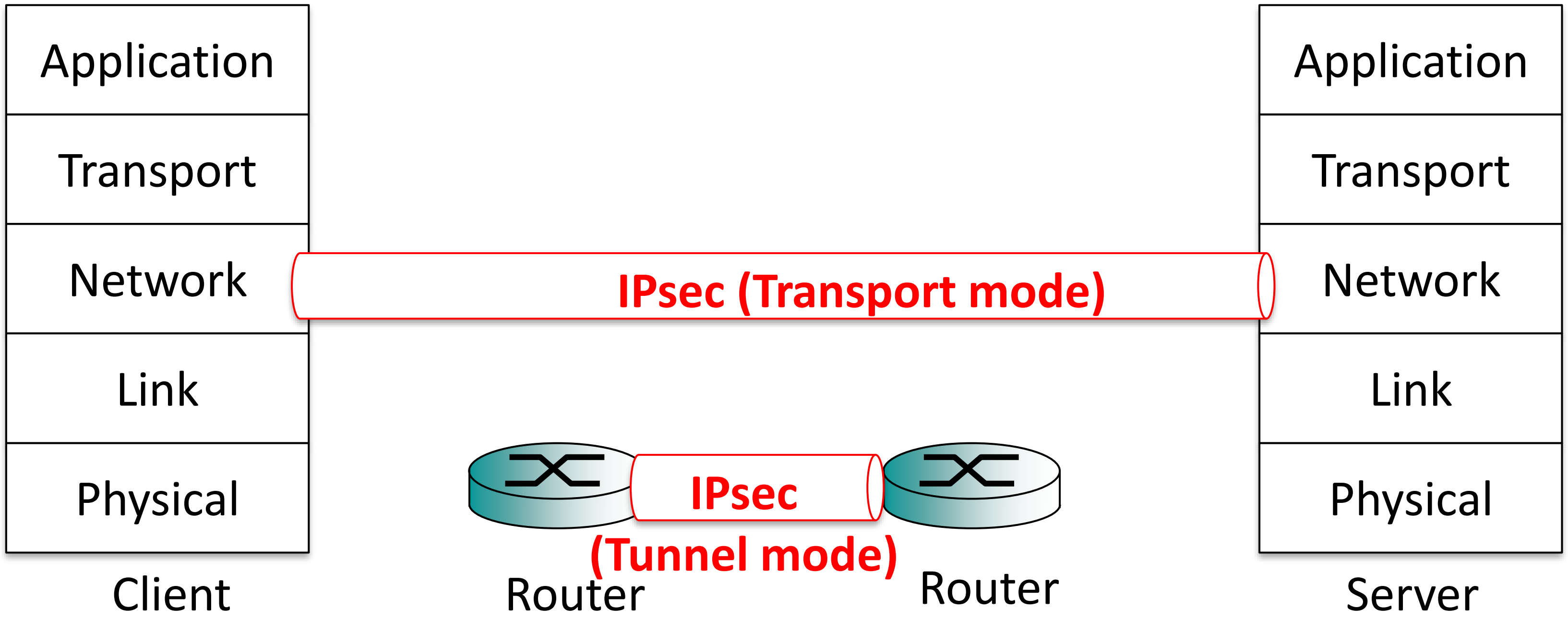
- A key concept of IPsec
  - □ One SA only governs security for unidirectional traffic
  - □ Two SAs are necessary for bidirectional traffic
- Uniquely identified by three parameters
  - □ Security parameter index (SPI)
  - □ IP destination address
  - □ Protocol identifier (ESP)

IPsec Primer: Encapsulating Security Payload (ESP)



IPsec Primer: Two IPsec Operation Modes

- Transport and Tunnel modes



IPsec Primer: Transport and Tunnel Modes

Transport Mode

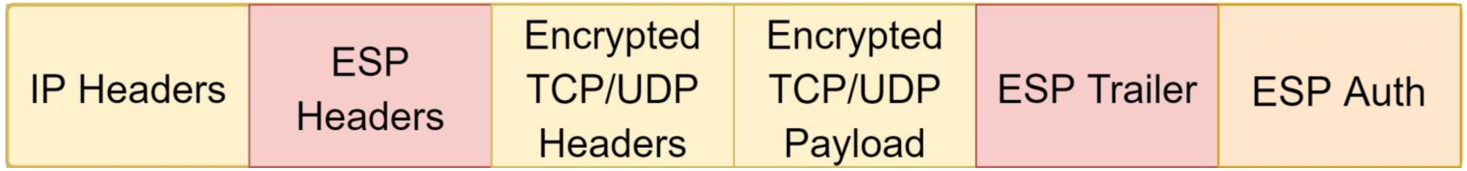
- Protects the payload of the IP packet
- Preserves the original IP header
- Used for end-to-end communication

Tunnel Mode

- Protects the entire IP packet
- Adds a new IP header to the packet
- Used for VPNs and gateway-to-gateway communication

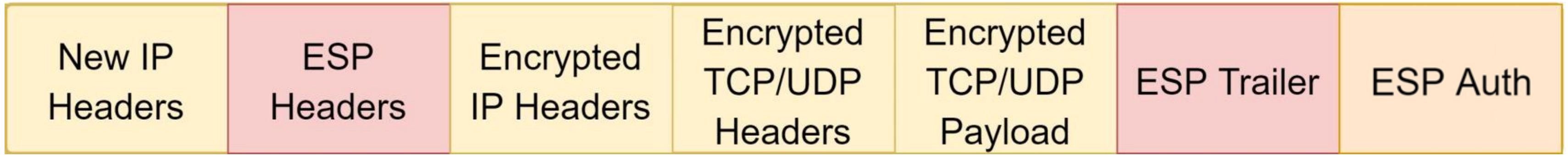
IPsec Primer: Data Encapsulation

- ESP Transport mode



IP Headers	ESP Headers	Encrypted TCP/UDP Headers	Encrypted TCP/UDP Payload	ESP Trailer	ESP Auth

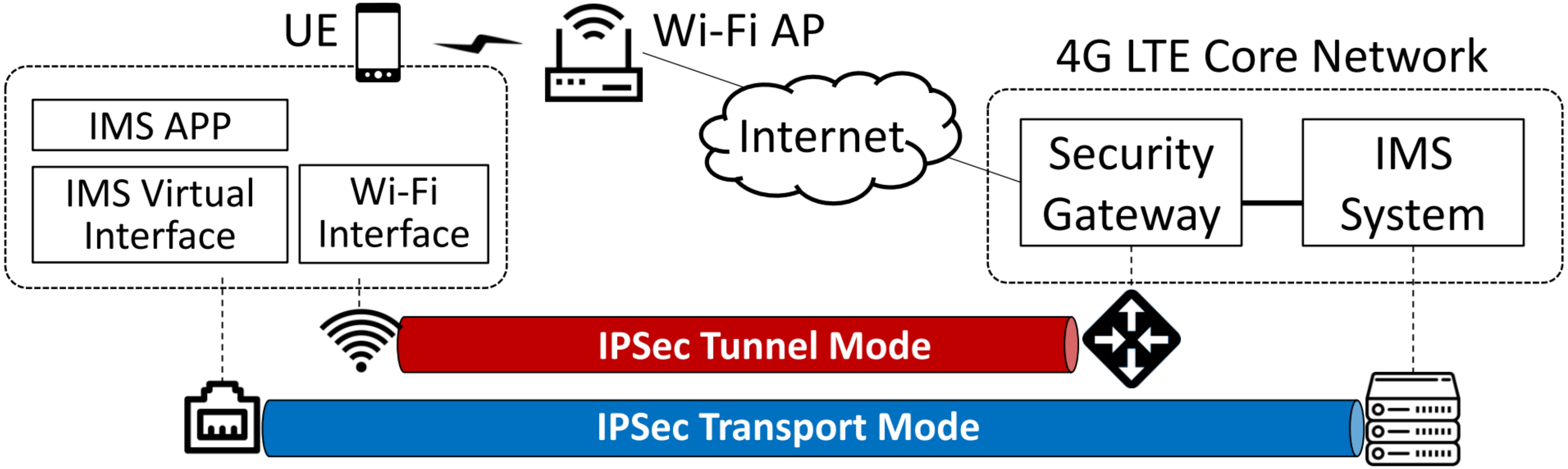
- ESP Tunnel mode



New IP Headers	ESP Headers	Encrypted IP Headers	Encrypted TCP/UDP Headers	Encrypted TCP/UDP Payload	ESP Trailer	ESP Auth

Case Study: VoWi-Fi with IPSec Protection

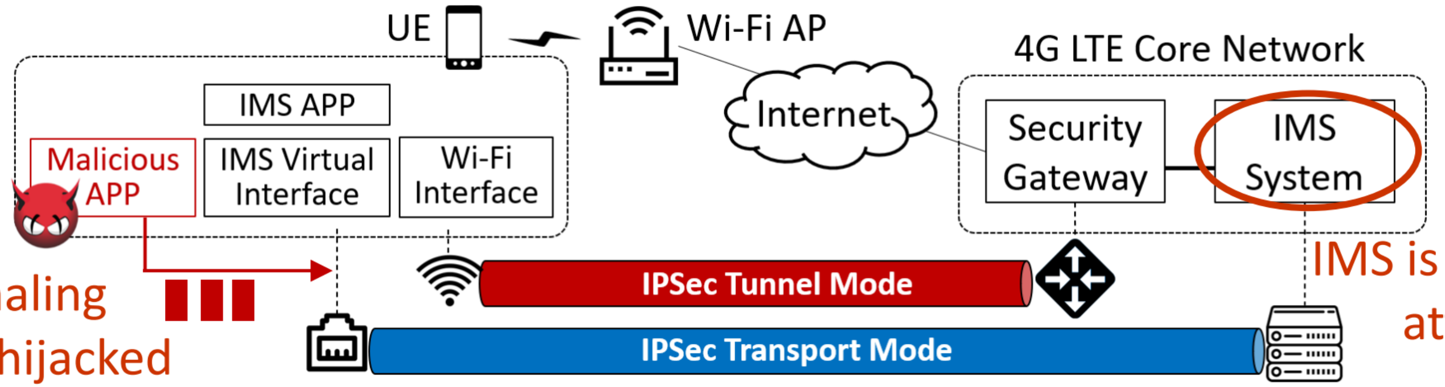
- IPSec protection over VoWi-Fi traffic traversing public domain



Case Study: VoWi-Fi with IPSec Protection (cont.)

- IPSec protection over VoWi-Fi traffic traversing public domain

However, they can be hacked!!



VoWi-Fi signaling session can be hijacked

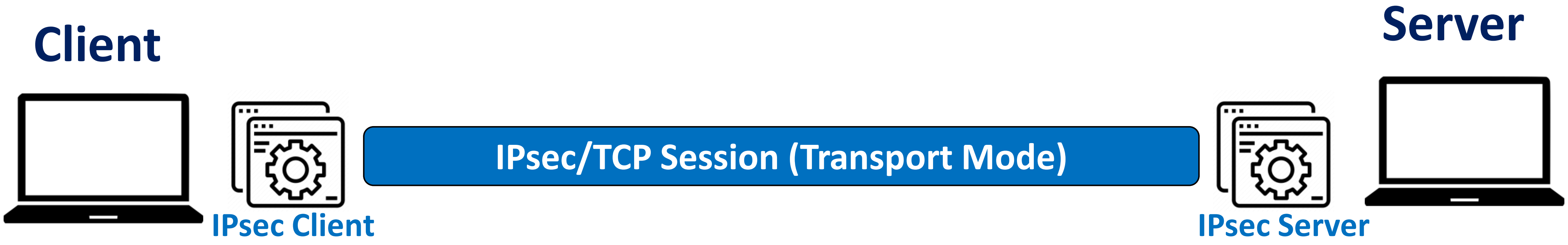
IMS is exposed to attackers

Attacker can manipulate IMS call service operation

IMS vulnerabilities can be exposed!!

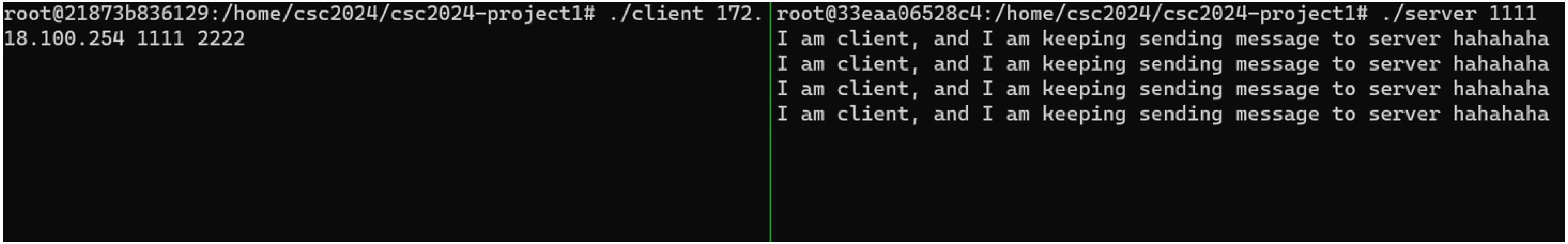
Environment Setup in this project

- Use two docker containers, designated as the client and the server, and establish the IPsec/TCP session between them
  - □ Please download the supplement from E3
  - □ Follows the step in the README.md to do the environment setup



Environment Setup in this project (cont.)

- Use two docker containers, designated as the client and the server, and establish the IPsec/TCP session between them
  - □ Please download the supplement from E3
  - □ Follows the step in the README.md to do the environment setup
  - □ If the setup is successful, the server will keep showing some messages

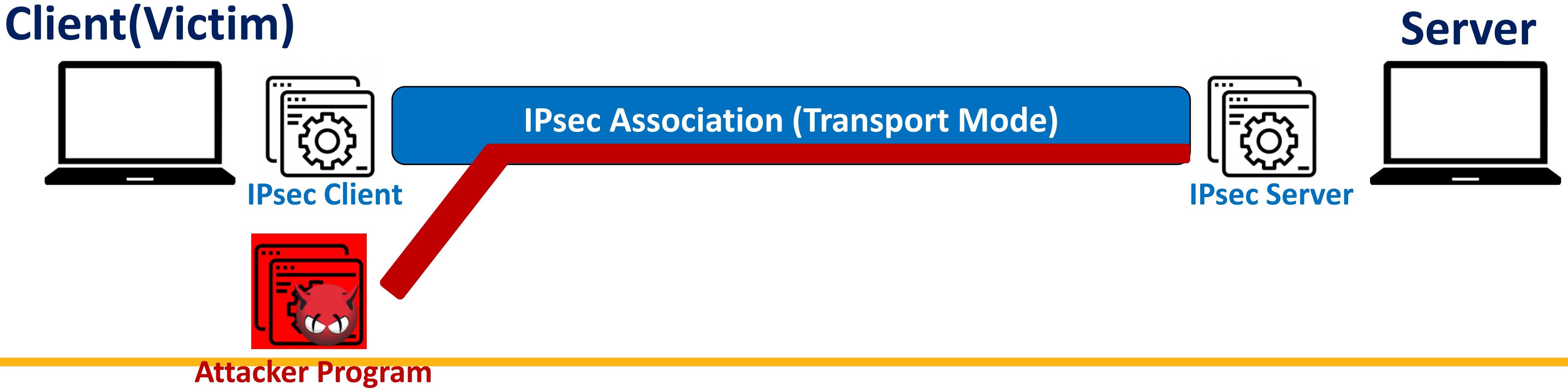


```
root@21873b836129:/home/csc2024/csc2024-project1# ./client 172.
18.100.254 1111 2222
```

```
root@33eaa06528c4:/home/csc2024/csc2024-project1# ./server 1111
I am client, and I am keeping sending message to server hahahaha
I am client, and I am keeping sending message to server hahahaha
I am client, and I am keeping sending message to server hahahaha
I am client, and I am keeping sending message to server hahahaha
```

IPsec/TCP Session Hijacking

- Execute provided programs to establish the IPsec/TCP session
- Develop an attacker program on Client to do hijacking
- Send specific flags to the server using the attacker program
  - □ If hijacking is successful, the server will reply to flags with correct responses



What should the attacker program do?

- Realtime information monitoring and collecting
  - Get session information from ESP and TCP headers, e.g., ESP SPI and TCP sequence number
  - Retrieve the IPsec SA from security association database (SADB), e.g., ESP secret key
    - Dump the key from SADB (RFC2367 Section 2.3.4 & 2.4 & 3.1.10)
- IPsec/TCP packet crafting
  - Fabricate IPv4/ESP/TCP headers, including all the fields and checksum
  - Generate ESP padding and authentication data
    - The Pad Length and Next Header fields must be right aligned with a 4-byte word (RFC4303 Section 2.4)

Todo Check List for Sample Codes

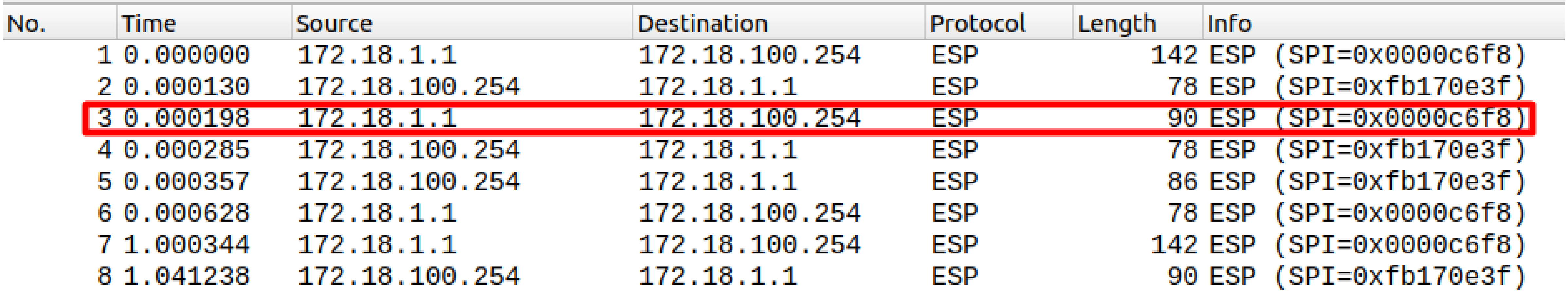
Method	Description
Session::Session	Fill struct sockaddr_ll addr which will be used to bind the socket
Session::dissect	Set payload
Session::dissectIPv4	Extract IPv4 header and payload, and check if receiving packet from remote
Session::dissectESP	Extract ESP header and payload, and track ESP sequence number
Session::dissectTCP	Extract TCP header, and track TCP header parameters
Session::encapsulateIPv4	Fill IPv4 header, and compute the checksum
Session::encapsulateESP	Fill ESP header, padding, and HMAC parameters
Session::encapsulateTCP	Fill TCP header, and compute the checksum
getConfigFromSADB	Fill struct sadb_msg msg which will be used to create PF_KEY_V2 socket
getConfigFromSADB	Extract SADB information from PF_KEY_V2 socket, and parse them

Three Verification Steps

- Step I: The server can receive fabricated IPsec packets belonging to the existing IPsec session (40%)
- Step II: The attacker program can correctly exchange TCP packets (data and ACK) with the server through the fabricated IPsec packets (30%)
- Step III: The attacker program can interact with the server with multiple handshakes (30%)

Step I: the server can receive fabricated IPsec packets belonging to the existing IPsec session

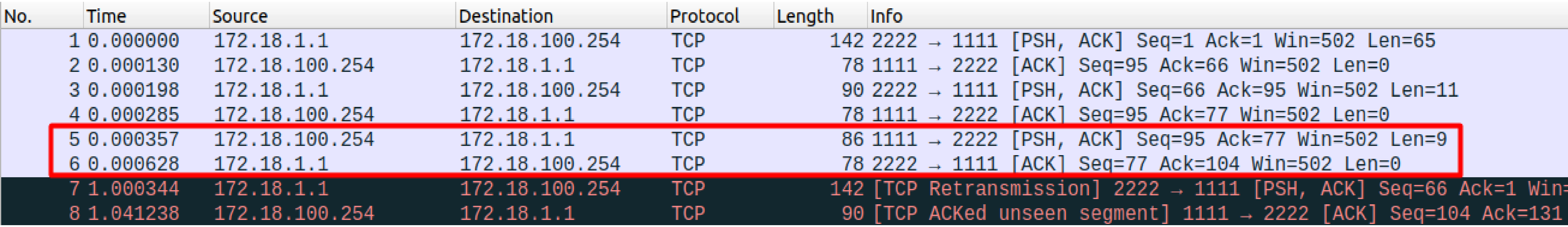
- An example
  - □ Client/Attacker program: 172.18.1.1
  - □ Server: 172.18.100.254



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	172.18.1.1	172.18.100.254	ESP	142	ESP (SPI=0x0000c6f8)
2	0.000130	172.18.100.254	172.18.1.1	ESP	78	ESP (SPI=0xfb170e3f)
3	0.000198	172.18.1.1	172.18.100.254	ESP	90	ESP (SPI=0x0000c6f8)
4	0.000285	172.18.100.254	172.18.1.1	ESP	78	ESP (SPI=0xfb170e3f)
5	0.000357	172.18.100.254	172.18.1.1	ESP	86	ESP (SPI=0xfb170e3f)
6	0.000628	172.18.1.1	172.18.100.254	ESP	78	ESP (SPI=0x0000c6f8)
7	1.000344	172.18.1.1	172.18.100.254	ESP	142	ESP (SPI=0x0000c6f8)
8	1.041238	172.18.100.254	172.18.1.1	ESP	90	ESP (SPI=0xfb170e3f)

Step II: the attacker program can correctly exchange TCP packets with the server through the fabricated IPsec packets

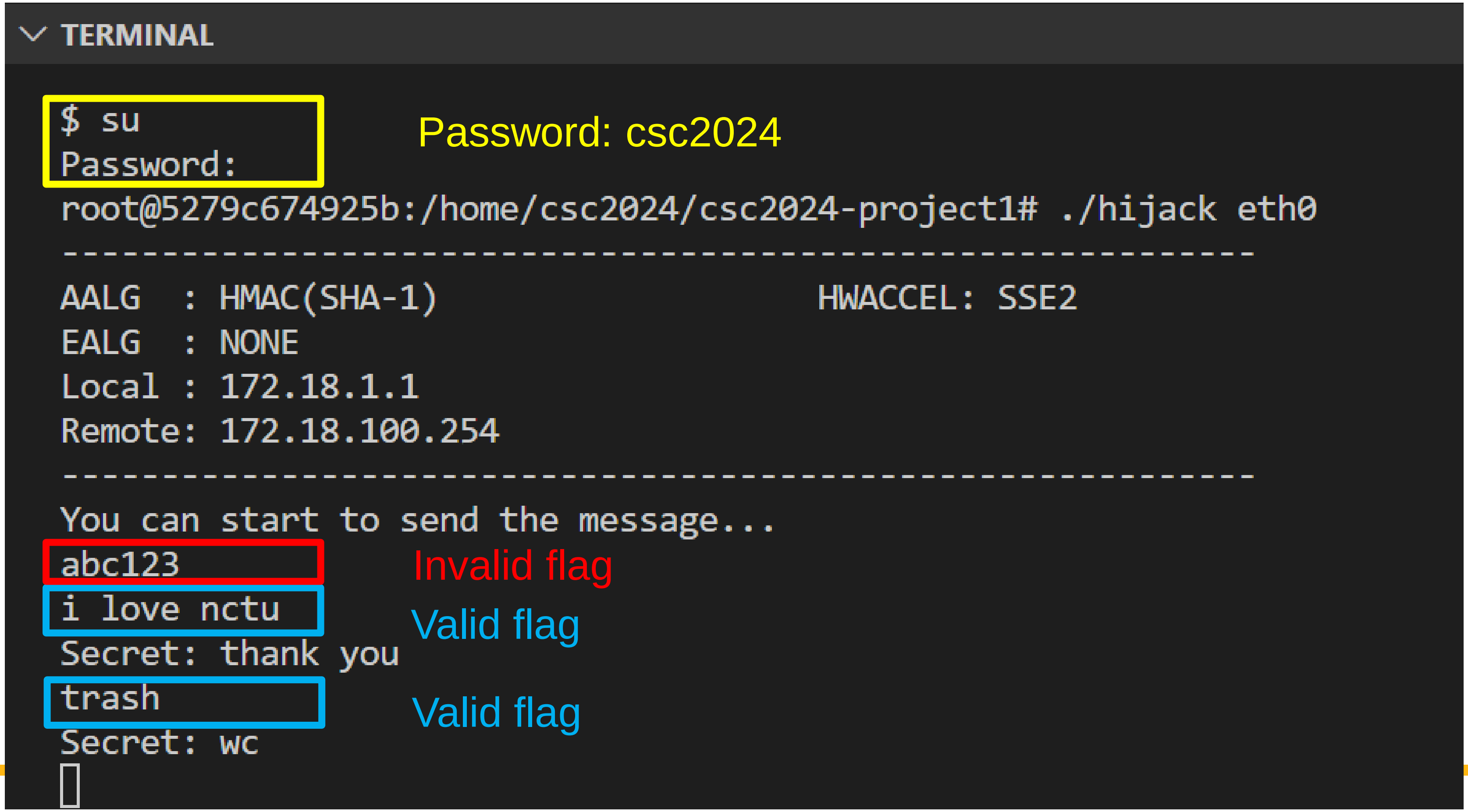
- An example
  - □ Client/Attacker program: 172.18.1.1
  - □ Server: 172.18.100.254
  - □ Modify the Wireshark preferences to enable dissecting of raw data



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	172.18.1.1	172.18.100.254	TCP	142	2222 → 1111 [PSH, ACK] Seq=1 Ack=1 Win=502 Len=65
2	0.000130	172.18.100.254	172.18.1.1	TCP	78	1111 → 2222 [ACK] Seq=95 Ack=66 Win=502 Len=0
3	0.000198	172.18.1.1	172.18.100.254	TCP	90	2222 → 1111 [PSH, ACK] Seq=66 Ack=95 Win=502 Len=11
4	0.000285	172.18.100.254	172.18.1.1	TCP	78	1111 → 2222 [ACK] Seq=95 Ack=77 Win=502 Len=0
5	0.000357	172.18.100.254	172.18.1.1	TCP	86	1111 → 2222 [PSH, ACK] Seq=95 Ack=77 Win=502 Len=9
6	0.000628	172.18.1.1	172.18.100.254	TCP	78	2222 → 1111 [ACK] Seq=77 Ack=104 Win=502 Len=0
7	1.000344	172.18.1.1	172.18.100.254	TCP	142	[TCP Retransmission] 2222 → 1111 [PSH, ACK] Seq=66 Ack=1 Win=
8	1.041238	172.18.100.254	172.18.1.1	TCP	90	[TCP ACKed unseen segment] 1111 → 2222 [ACK] Seq=104 Ack=131

Step III: Multiple Handshake Tests with Three Flags

- An example with an invalid flag and two valid flags



```
$ su
Password:
root@5279c674925b:/home/csc2024/csc2024-project1# ./hijack eth0
------------------------------------------------------------
AALG  : HMAC(SHA-1)                     HWACCEL: SSE2
EALG  : NONE
Local : 172.18.1.1
Remote: 172.18.100.254
------------------------------------------------------------
You can start to send the message...
abc123
i love nctu
Secret: thank you
trash
Secret: wc
```

Password: csc2024

Invalid flag

Valid flag

Valid flag

Important: How to Prepare Your Attack Program?

- Must provide a **Makefile** which compiles your source codes into one executable file, named **hijack** **(Missing: -20%)**
- Your attacker program shall be run in the container built by provided docker file and docker compose yaml
  - TA may copy your source code file to the TA's container to do some testing
- Must **use given program's framework**, **otherwise no any credit**
- Not recommend you use docker with WSL as the backend because it may not support creating PF_KEY_V2 socket

Project Submission

- Due date: 3/27 11:55pm
- Makeup submission and demo after the final (totally 75 points at most)
- Submission rules
  - Put your source code files into a directory and name it using your student ID(s)
    - If your team has two members, please concatenate your IDs separated by "-"
  - Zip the directory and upload the zip file to E3
  - A sample of the zip file: 01212112-02121221.zip, you can use "zipinfo -1" to examine the format (Wrong file name or format will result in 10 points deduction)
    - 01212112-02121221/
    - 01212112-02121221/Makefile
    - …
- Teamwork is allowed, up to two members for each team

Project Demo

- Demo date: 3/29
- TA will prepare two containers to run as the client and the server, respectively
  - Your zip file will be put into the client
- You will
  - be asked to launch an IPsec/TCP hijacking attack
  - be only allowed to “make” to compile all your files, and run your attack binary programs or scripts
  - be not allowed to modify your codes or scripts in the demo
  - be not allowed to install any programs or libraries in the container
  - be asked some questions
  - be responsible to show the outcome to TA and explain why you have successfully achieved the goals

Hint 1: Dump the key from SADB

- The message format in SADB

struct sadb_msg	sadb_ext	sadb_ext	…

- Each extension begins with a 16-bit ext_len and a 16-bit ext_type field

- Getting the key from the extension with sadb_ext_type “SADB_EXT_KEY_AUTH”

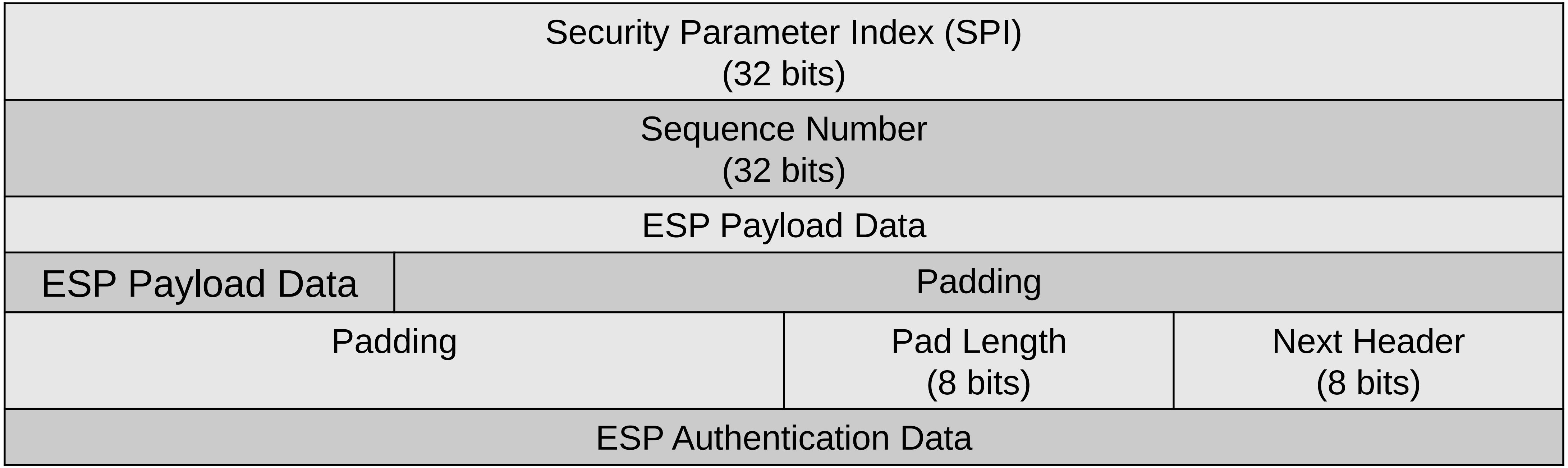
Hint 2: Fabricate packets

- IPv4 header format

<table>
<tr><td>Version
(4 bits)</td><td>IHL
(4 bits)</td><td colspan="2">Type of Service
(8 bits)</td><td colspan="4">Total Length
(16 bits)</td></tr>
<tr><td colspan="4">Identification
(16 bits)</td><td>Flags
(3 bits)</td><td colspan="3">Fragment Offset
(13 bits)</td></tr>
<tr><td colspan="2">Time to Live
(8 bits)</td><td colspan="2">Protocol
(8 bits)</td><td colspan="4">Header Checksum
(16 bits)</td></tr>
<tr><td colspan="8">Source Address
(32 bits)</td></tr>
<tr><td colspan="8">Destination Address
(32 bits)</td></tr>
<tr><td colspan="8">Options
(multiple of 32 bits)</td></tr>
</table>

Hint 2: Fabricate packets (cont.)

- ESP format



Security Parameter Index (SPI)
(32 bits)

Sequence Number
(32 bits)

ESP Payload Data

ESP Payload Data

Padding

Padding

Pad Length
(8 bits)

Next Header
(8 bits)

ESP Authentication Data

Hint 2: Fabricate packets (cont.)

- TCP header format

<table>
<tr><td colspan="8">Source Port
(16 bits)</td><td>Destination Port
(16 bits)</td></tr>
<tr><td colspan="9">Sequence Number
(32 bits)</td></tr>
<tr><td colspan="9">Acknowledge Number
(32 bits)</td></tr>
<tr><td>Header
Length
(4 bits)</td><td>Reserved
Bits
(6 bits)</td><td>U
R
G</td><td>A
C
K</td><td>P
S
H</td><td>R
S
T</td><td>S
Y
N</td><td>F
I
N</td><td>Window Size
(16 bits)</td></tr>
<tr><td colspan="8">Checksum
(16 bits)</td><td>Urgent Pointer
(16 bits)</td></tr>
<tr><td colspan="9">Options</td></tr>
</table>

Questions?