Google

Seeing Inside The Encrypted Envelope

About Me

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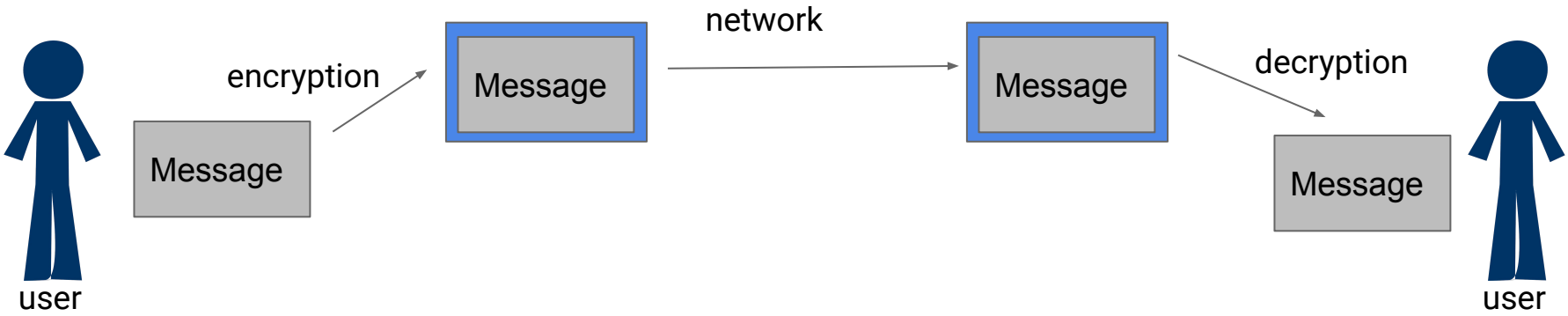
- Project Zero member
- Previously did mobile security on Android and BlackBerry
- Messaging enthusiast

The Problem

- Most remote attack surfaces accept encrypted input
- Attack surfaces that process recently decrypted data are valuable because the server can’t analyze or filter content
- Encryption schemes are usually complicated and/or proprietary

My goal


user
Message
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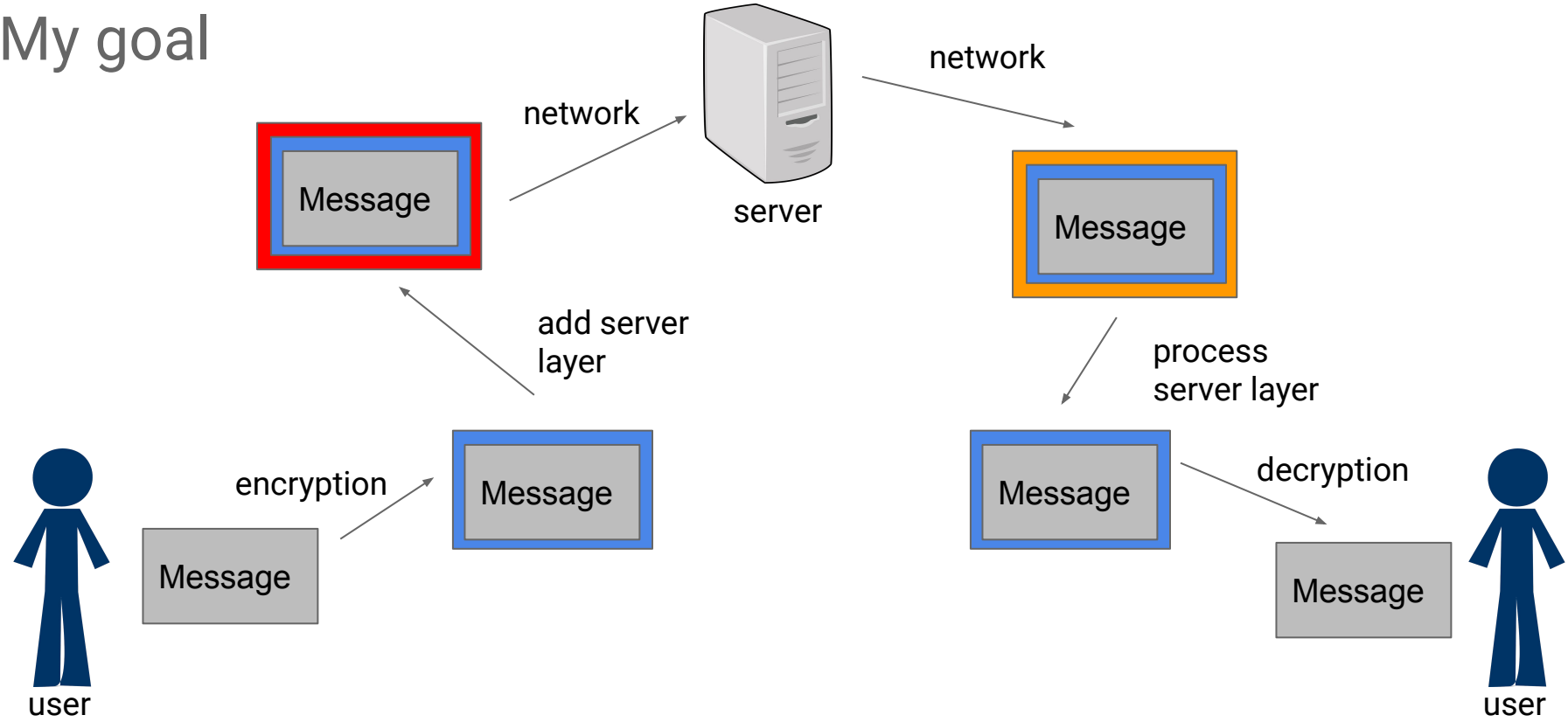
My goal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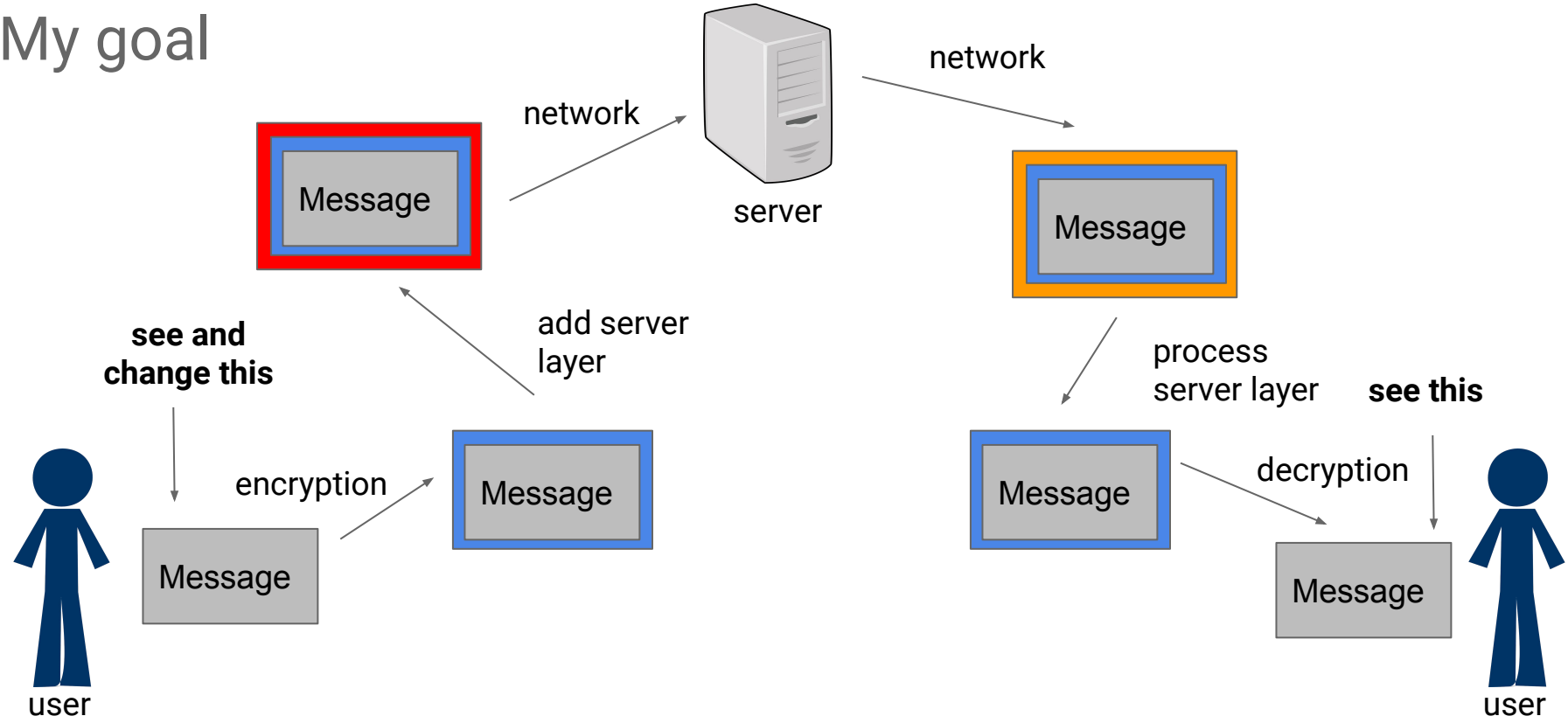
My goal


network
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decryption
user
user

Targets

General Considerations

- Platform (mobile versus desktop)
- Open versus closed source
- Custom versus proprietary protocols
- Best effort versus real-time

Strategies

- Intercept over the network and decrypt
- Write or use a client
- Hook the target

Intercepting Traffic

- Generally very difficult strategy unless standard protocols are used
  - Documentation generally lacks details
- Where are you getting the key from?
- Removing crypto function is a possibility
  - Have a ‘special’ libcrypto
  - Make it memcpy or do nothing
  - Can be problematic when reporting bugs

Create a Standalone Client

- This is typically the best and most stable solution
- Heavy development cost
- Easy to distribute
  - Risk of blocking

Using Existing Clients

- This can work if a very good open source client exists
- Most unofficial clients focus on functionality as opposed to coverage
- Changing an open-source client to be suitable for security testing can be time-consuming
- Often use pieces of open source clients for decoding
- Example: Facebook and WhatsApp

Example: WebRTC

- Wrote a standalone client that could start a call with any backend
- Used it to test browsers and Facebook Messenger
- ~ 1 week dev time
- Had difficulty keeping it up to date
- Eventually wrote a command line client that could fuzz on a single device

Hooking

- Hooking functions is a practical low cost solution
  - Often a good way to start to see how buggy software is
- Can be error prone
  - Software updates are a challenge
- Good coverage
- Distribution can be challenging

Hooking

- Two slightly different methodologies
  - Use a debugger-like tool to hook at runtime
  - Modify the binary
- Modification is generally better for performance and stability
- Runtime hooking is generally easier

Examples

- Runtime hooking
  - iMessage
- Application modification
  - Facebook Messenger and WhatsApp signalling (Android application)
  - WhatsApp calling (Android native changes)
  - FaceTime (proprietary all the way down)

iMessage

- Samuel Groß wrote iMessage sending and intercepting client
- Used Frida to hook incoming and outgoing messages

Frida

- Python-based real-time native function hooking framework
  - Can also hook Android Java with limitations
- Works on Android, iPhone, Mac, Linux, etc.
- Just run a binary on the target and attach it to the host via USB
- Actual hooking is written in JavaScript
  - Causes some problems in Objective-C

iMessage Send Script

```
var jw_encode_dictionary_addr =
Module.getExportByName(null,
"JWEncodeDictionary");
send("Hooking JWEncodeDictionary" +
jw_encode_dictionary_addr);
Interceptor.attach(jw_encode_dictionary_addr, {
    onEnter: function(args) {
   var dict = ObjC.Object(args[0]);
```

iMessage Send Script

```
        send(dict.toString())
        var t = dict.objectForKey_("t")
        if (t == "REPLACEME") {
            var newDict =
ObjC.classes.NSMutableDictionary.dictionaryWith
Capacity_(dict.count());
            newDict.setDictionary_(dict);
            newDict.setObject_forKey_("new
message", "t");
```

Android Application Example

- Facebook Messenger
  - Very large, very complicated application
  - It’s usually not necessary to use all of these strategies

Basic Idea

- Find where message is encrypted
- Insert smali code after the message has been serialized, but before it has been signed or encrypted
- Code sends message to remote server, where it can be changed
- Altered message gets sent to test device

Finding the Encryption Point

- Started by decompiling the application APK using apktool
- Get smali files out
- Typically obfuscated
- Android applications contain a lot of unused and rarely used code

```
.method public constructor
<init>(LX/8A2;LX/0Gl;LX/0Gl;LX/89x;LX/1q1;LX/1Xs;LX/0wj;LX/0Gl;
LX/1pr;LX/0wQ;LX/0oS;LX/0dK;LX/0wO;LX/0Gl;LX/1q5;LX/0wm;)V
    .locals 10
    invoke-direct {p0}, Ljava/lang/Object;-><init>()V
    iput-object v9, p0, LX/89y;->c:LX/8A2;
    iput-object v7, p0, LX/89y;->d:LX/0Gl;
    iput-object v6, p0, LX/89y;->e:LX/0Gl;
    iput-object v5, p0, LX/89y;->f:LX/89x;
    iput-object v4, p0, LX/89y;->g:LX/1q1;
    iput-object p4, p0, LX/89y;->h:LX/1Xs;
    iput-object v1, p0, LX/89y;->i:LX/0wj;
    iput-object v0, p0, LX/89y;->j:LX/0Gl;
```

Strategies

- Look for known libraries
  - Libsignal
  - Java crypto
- Focus on natives
- Log entries

Known Libraries

- Most E2E encrypted messengers include libsignal
- Unfortunately, full feature set is not used
- Putting in a stub where libsignal encrypts messages (based on Signal source) did not work on most messengers

Java Crypto Libs

- Cheap trick:
  - Make a build of Android that has a stub in javax.crypto.Mac
  - Make the stub send the digest only when it can access a file in the sandbox of the app you’re testing
  - Will get a lot of stuff that isn’t messages, plus sometimes messages
- Works on about half of messengers

Java Crypto Libs

- Also possible to put log entry that outputs Java stack in Java crypto libs
- Can help you find where the app is encrypting the message
- Relies on the app actually using Java crypto
- Apps often implement their own encryption (wrap a native library), but usually use Java for signing
- Once output stacks in System.arraycopy when I was desperate

Java Crypto Libs

- Can also search smali, but no guarantee stuff gets called
  - Looking for obfuscated functions with byte array parameters worked on WhatsApp
- Can also hook Java crypto with Frida, but doesn’t work well on all devices

Natives (JNI)

- Java Native Interface calls cannot be obfuscated (easily)
- Calls with ‘encrypt’ in the name are good candidates for stub locations
  - Stubs are smali wrappers for the native function
- Messaging encryption is usually native
- Be careful to separate file encryption from network encryption
- Made a script that outputs log entries for every native call

JNI Question

In a Java application, can native code be run without a JNI call?

No.

- JNI can start threads, etc, but native code always starts with a JNI call in an Android Java application

Log Entries

- Some apps have a lot of helpful log entries (and some don't)

```
    const/4 v10, 0x0
    monitor-enter v4
    :try_start_0
    iget-object v0, v4, LX/8B3;->d:Ljavax/crypto/Mac;
    if-nez v0, :cond_10
    sget-object v1, LX/8B3;->a:Ljava/lang/Class;
    const-string v0, "Could not verify Salamander signature -
no SHA256HMAC"
    invoke-static {v1, v0},
LX/00T;->b(Ljava/lang/Class;Ljava/lang/String;)V
    :try_end_0
    .catchall {:try_start_0 .. :try_end_0} :catchall_0
```

Log Entries

- Signature verification failure is a good log entry to look for
- You can add your own log entries

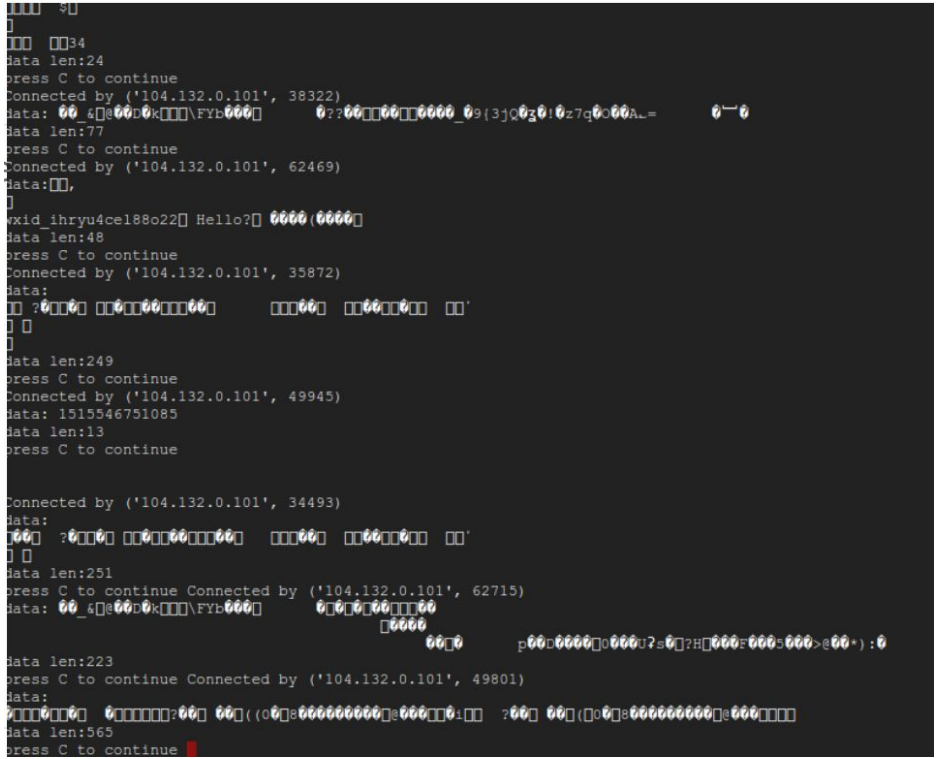
More About Message Encryption

- Apps usually have more than one location where they encrypt messages
  - Messages
  - Attachments
  - Typing/presence indicator
  - Notification content
  - Usually need to add multiple stubs
  - Can add stubs away from encryption too

End Result

- Facebook
  - Added smali stubs in several locations, including wrapping native encryption in smali
- WhatsApp
  - Added smali stub at a single location, far from natives
  - Also altered serialization code at various locations to alter certain message fields without understanding the format (for example, testing directory traversal by changing path generation)

Messages!


data len:24
press C to continue
Connected by ('104.132.0.101', 38322)
data len:77
press C to continue
Connected by ('104.132.0.101', 62469)
data len:48
press C to continue
Connected by ('104.132.0.101', 35872)
data len:249
press C to continue
Connected by ('104.132.0.101', 49945)
data: 1515546751085
data len:13
press C to continue
Connected by ('104.132.0.101', 34493)
data len:251
press C to continue Connected by ('104.132.0.101', 62715)
data len:223
press C to continue Connected by ('104.132.0.101', 49801)
data len:565
press C to continue

Android Native Example

- WhatsApp calling required intercepting messages in the native code

WhatsApp Calling

- Looked at Android App
- No symbols, but log entries from libsrtp and PJSIP
- Identified memcpy from packet to buffer before encryption (looked for srtp_protect log entries)

WhatsApp Calling

- Wrote a Frida script that hooked all memcpy instances
- Frida is awesome!

```
hook_code =""

                    Interceptor.attach (Module.findExportByName (
                "libc.so", "read"), {

                        onEnter: function (args) {

                        send (Memory.readUtf8String (args [1]));

                     },
```

WhatsApp Calling

- Frida is too slow to make a call without a lot of lag
  - Good for debugging binary changes though
- Changed specific memcpy to point to function I wrote in ARM64
- Assembly of my function overwrote GIF transcoder

WhatsApp Calling

- Original branch to malloc was BL instruction
- Used the ARM branch finder to make it point to my function instead http://armconverter.com/branchfinder/
- My function calls dlopen, dlsym and then a function in libnatalie.so

WhatsApp Calling

- Had issues with calls disconnecting, turned out I was corrupting a used register
- After a few fixes could log and alter incoming packets
- Replaying packets by pure copying did not work

RTP Protocol

Bit Offset	0-1	2	3	4-7	8	9-15	16-31
0	Version	Padding	Ext.	CSRC Count	Marker	Payload Type	Sequence Number
32	Timestamp						
64	Synchronization Source (SSRC) Identifier						
96	Contributing Source (CSRC) Identifier						
96+32*CC	Payload						

Interesting Parts of RTP Headers

- SSRC is a random identifier that identifies a stream
  - WhatsApp cannot be limited to a single stream
- Payload type is an identifier that identifies content type, and is consistent

WhatsApp Calling

- WhatsApp has FOUR RTC streams, even when muted
- Luckily, they have different payload types
- Fixing ssrc and sending logged packets worked

FaceTime

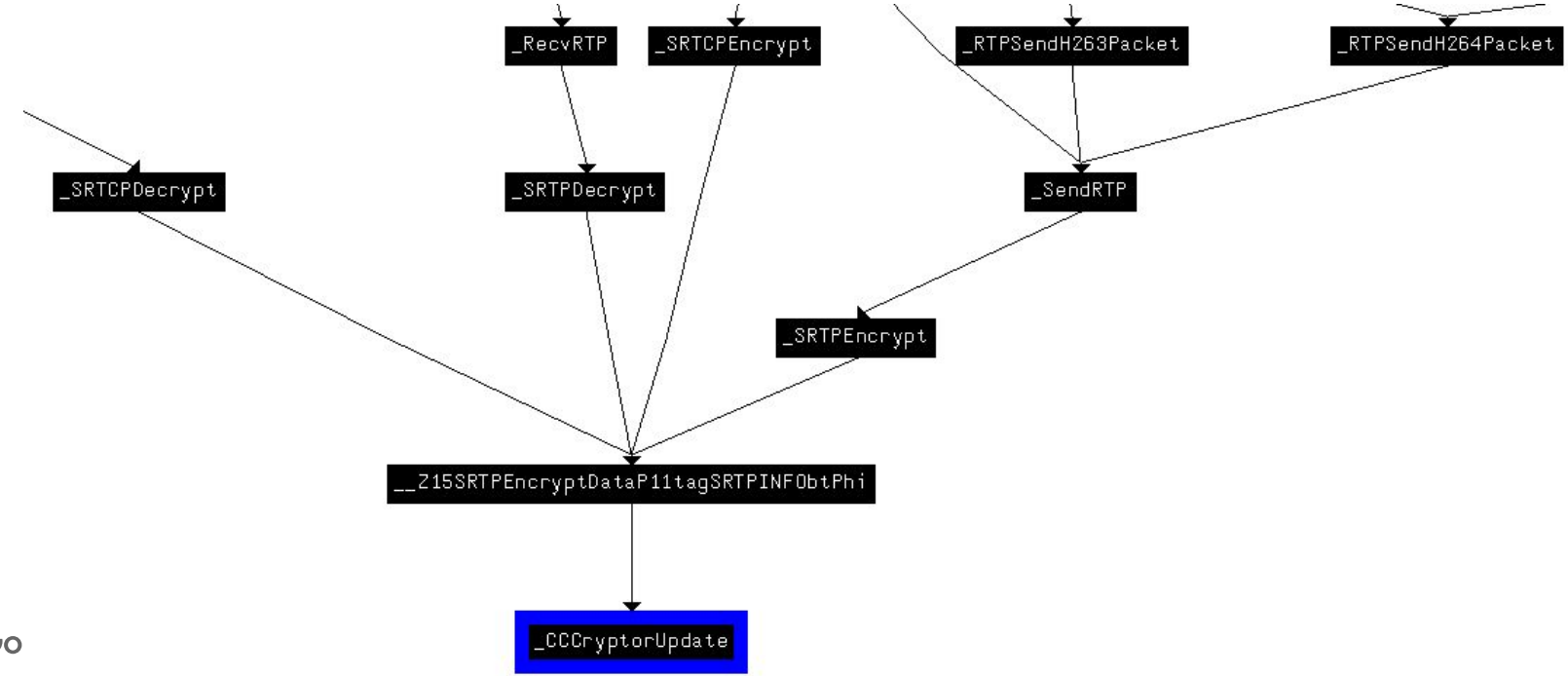
- Limited open-source components
- Runs on Mac
- Needed to modify binary to log packets

FaceTime

- FaceTime is closed-source and proprietary
- Needed to modify binary to log packets

FaceTime Encryption

- Used IDA to identify call to encryption function



Hooking Functions on MacOS

- CCCryptorUpdate seemed a good candidate for recording RTP
- DYLD_INTERPOSE can be used to redirect library calls on Macs
- Requires setting an environment variable
  - This isn’t possible for AVConference, which is started as a daemon

Hooking Functions on MacOS

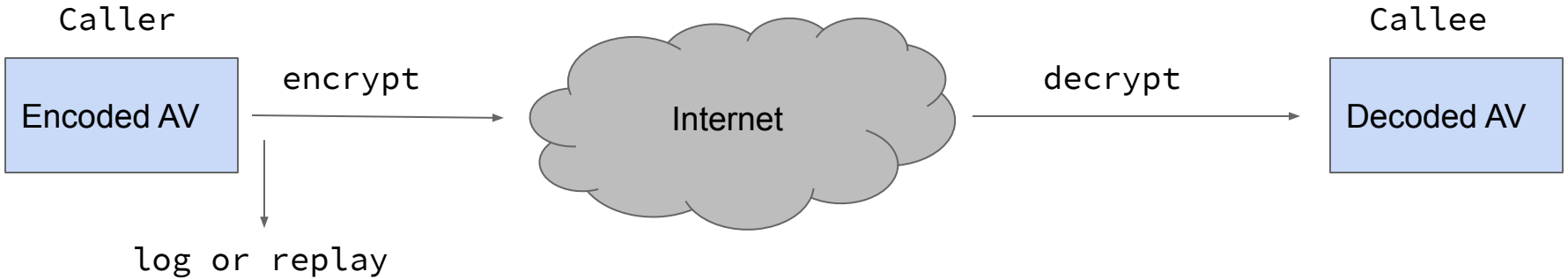
- DYLD_INTERPOSE can also be called in the static section of a library loaded by a Mac binary
- Found insert_dylib on github https://github.com/Tyilo/insert_dylib
- Inserted static library that hooked CCCryptorUpdate

```
DYLD_INTERPOSE(mycryptor, CCCryptorUpdate);

CCCryptorStatus mycryptor(
   CCCryptorRef cryptorRef, const void
*dataIn,
   size_t dataInLength, void *dataOut,

   size_t dataOutAvailable,size_t
*dataOutMoved) {
```

Hooking Functions on MacOS

- Tried making a call
- Needed some refinement
  - Limited hooking to functions that sent RTP
  - Added a spinlock
  - Patched binary to pass length
- Could alter RTP in real time, but replay did not work!

Hooking Functions on MacOS



Investigating RTP Packets

- Read through _SendRTP function to figure out packet generation
- Discovered RTP headers were created well after encryption

Bit Offset	0-1	2	3	4-7	8	9-15	16-31
0	Version	Padding	Ext.	CSRC Count	Marker	Payload Type	Sequence Number
32	Timestamp						
64	Synchronization Source (SSRC) Identifier						
96	Contributing Source (CSRC) Identifier						
96+32*CC	Payload						

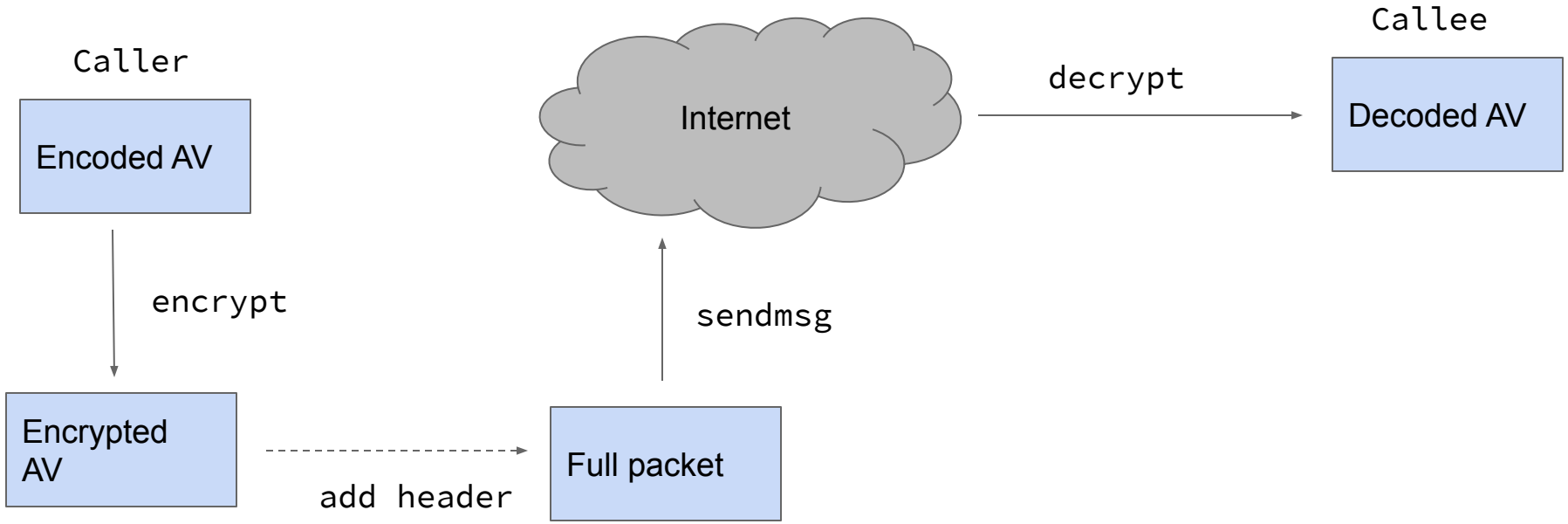
Interesting Parts of RTP Headers

- SSRC is a random identifier that identifies a stream
  - FaceTime cannot be limited to a single stream
- Payload type is a constant that identifies content type
- Extensions are extra information that is independent of the stream data
  - Screen orientation
  - Mute
  - Quality
  - Wait a sec, these totally depend on stream data

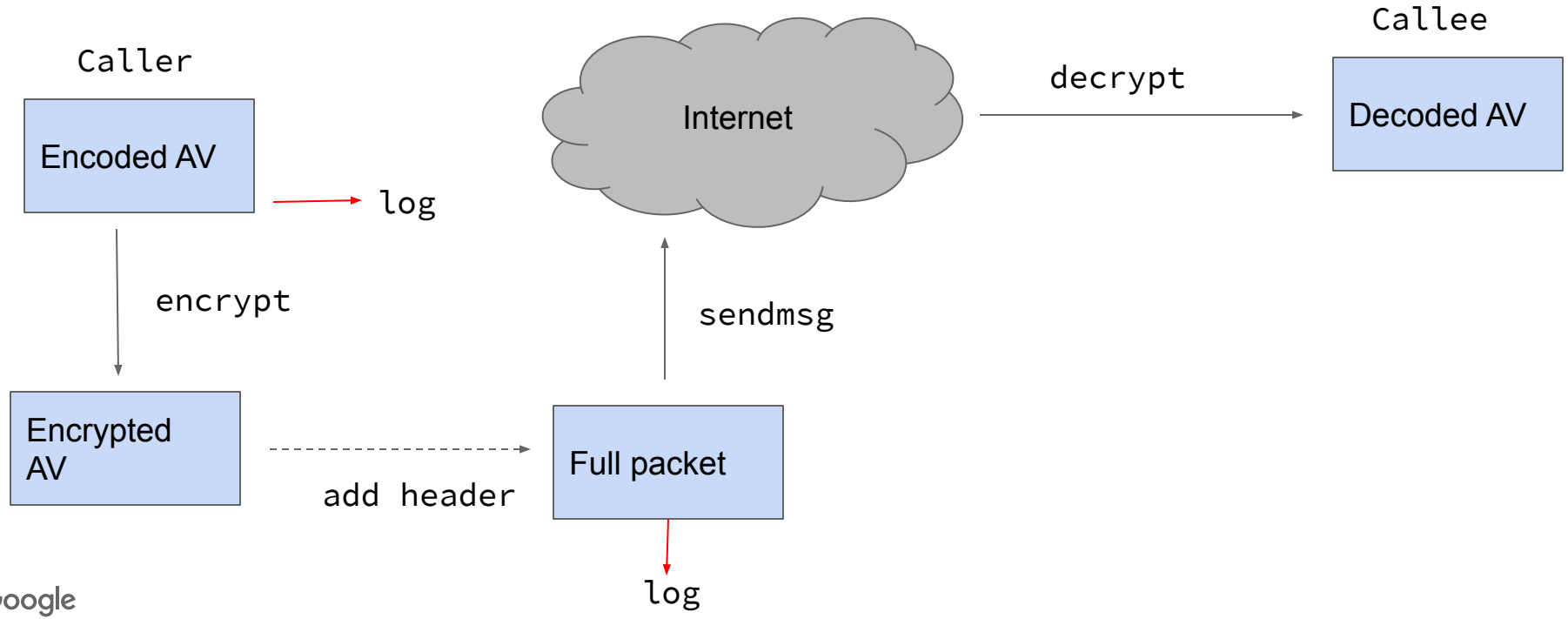
Hooking Headers?

- Tried replaying with existing headers
- Hooked sendmsg to capture and log header
  - Needed to tie encrypted message to header
  - sendmsg NOT called on packets in the same order as encryption (even with a spinlock)
  - Need to ‘fix’ SSRC and sequence number

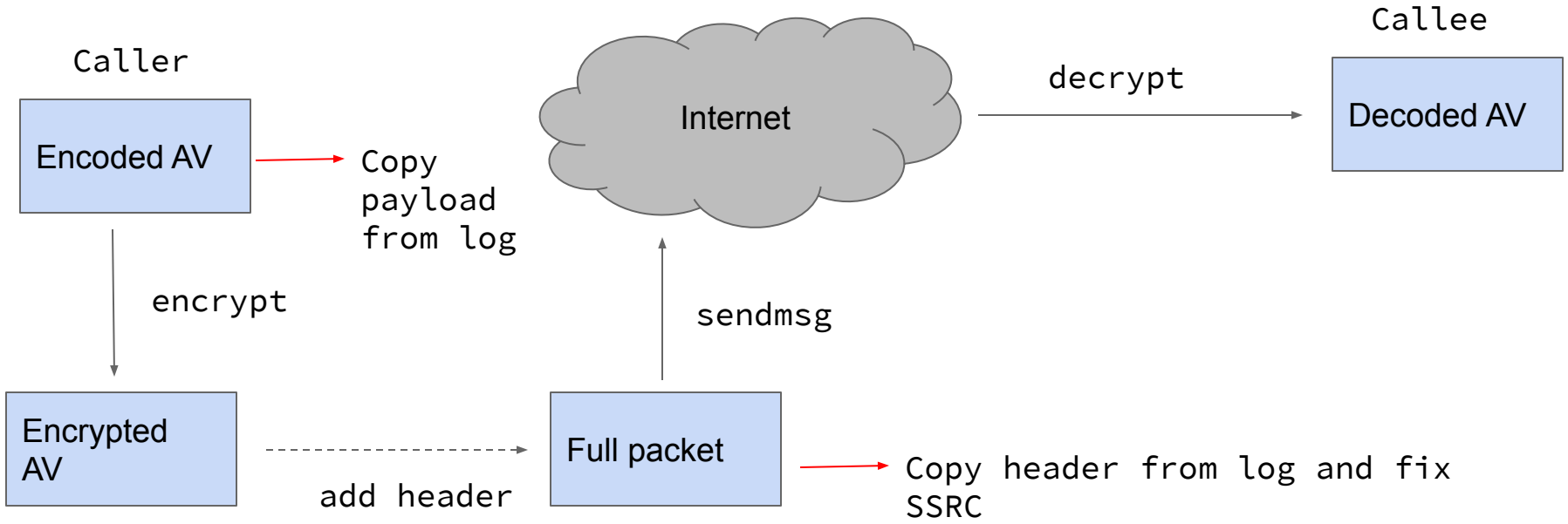
Fixing headers



Fixing headers (send)



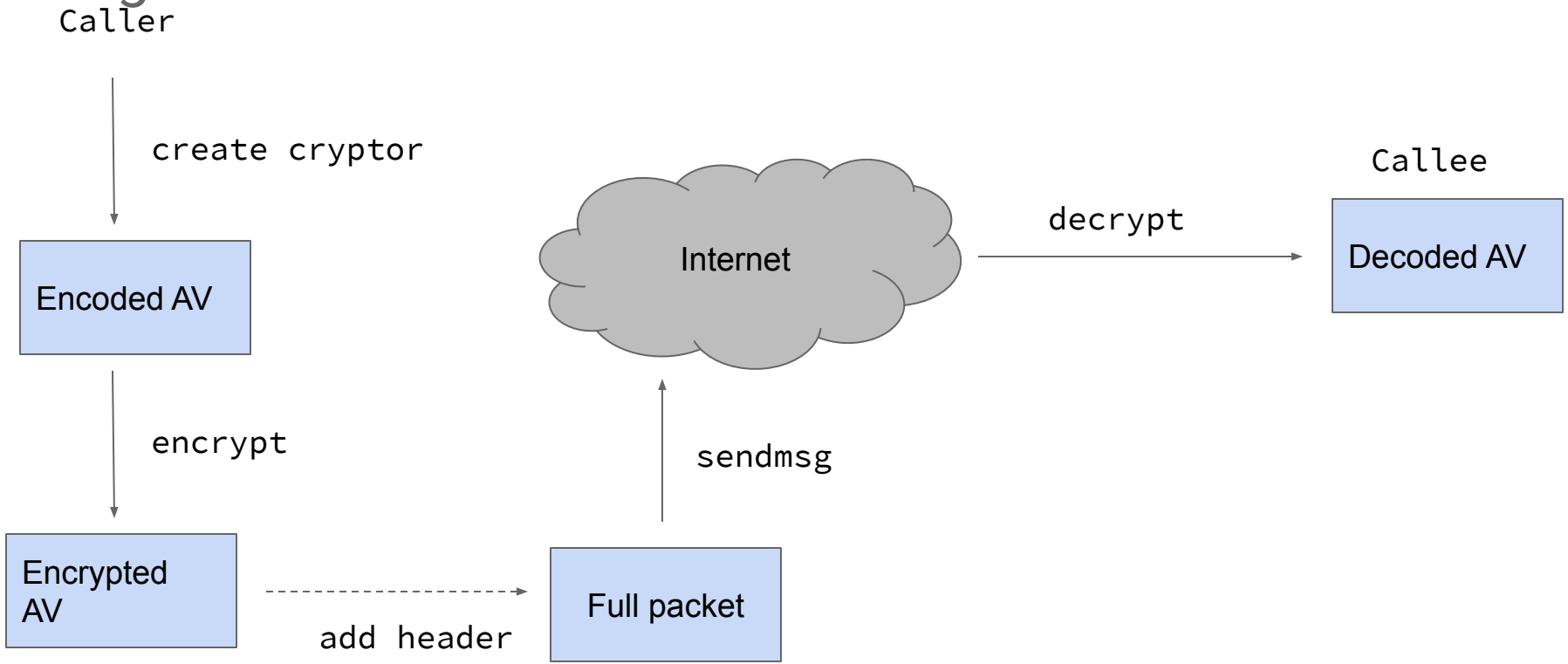
Fixing headers (replay)



Still Didn’t Work

- Patched endpoint to remove encryption
  - This worked, but can’t do it on an iPhone
  - Audio data clearly getting corrupted in decryption
- Created a cryptor queue for each SSRC, and encrypted the data in order
- Discovered encryption is XTS with sequence number as counter
- Fixed seq number counter

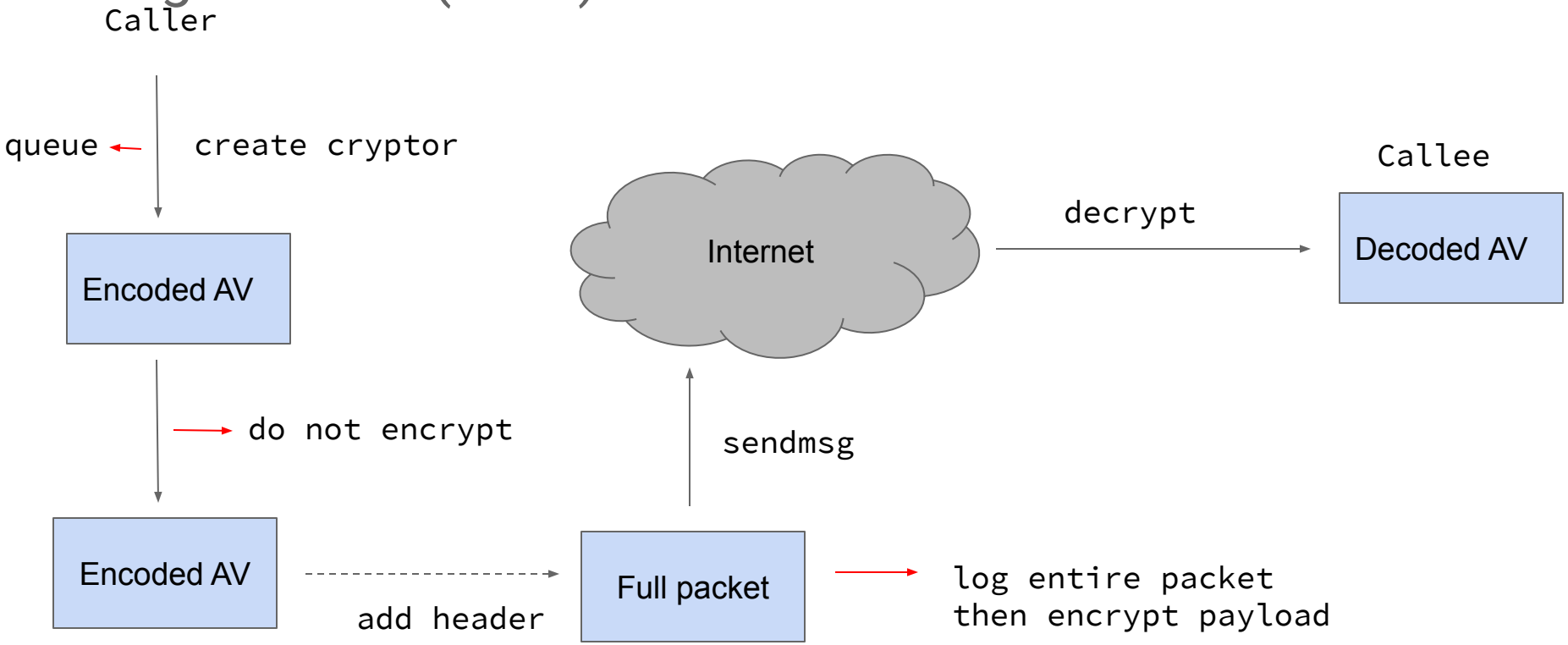
Fixing headers



Steps to Log

- Hook CCCryptorCreate to log cryptors as they are created
  - Store cryptors by thread in queues
- Hook CCCryptorUpdate, and prevent packets from being encrypted
- Hook sendmsg, log unencrypted packet, and then encrypt it using the cryptor from the queue

Fixing headers (send)



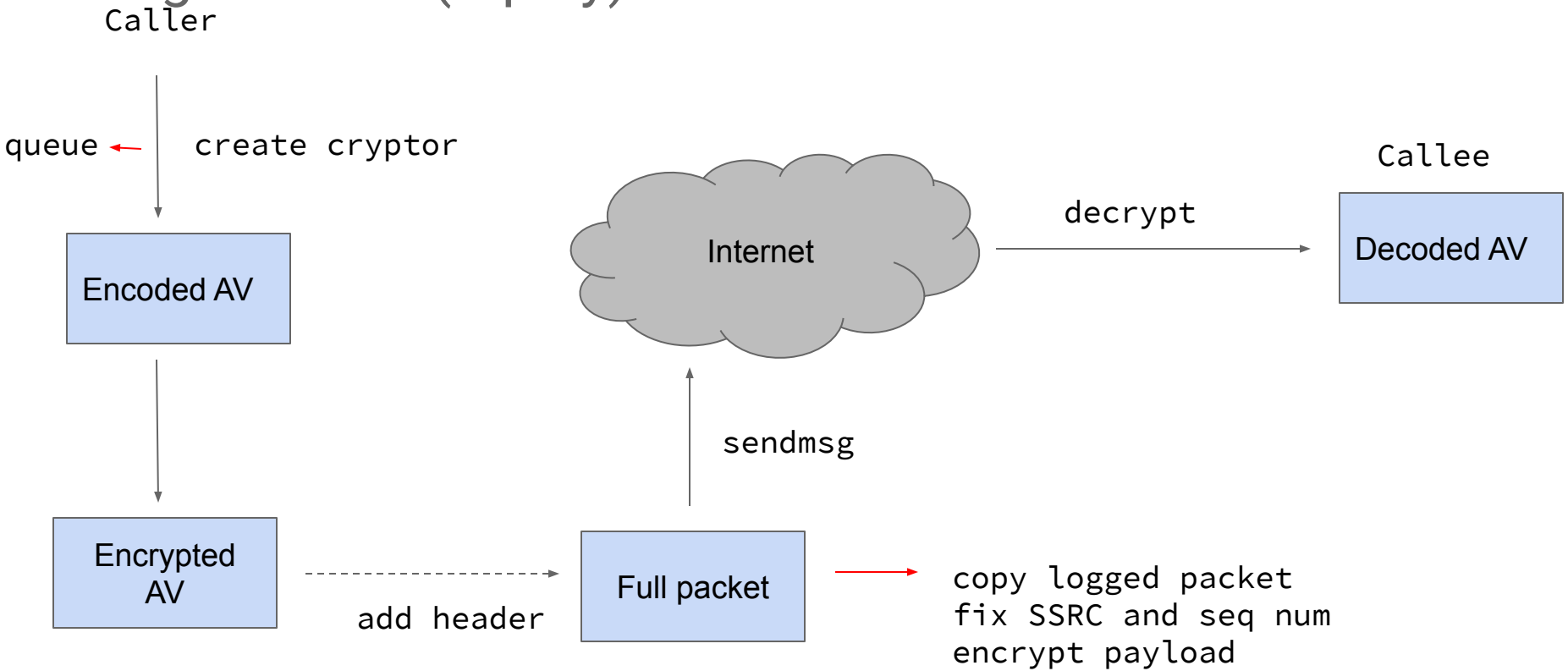
Steps to Replay

- Hook CCCryptorCreate to log cryptors as they are created
  - Store cryptors by thread in queues
- Hook sendmsg, save current ssrc and sequence number if it hasn’t been seen before
- Copy logged packet into current packet

Steps to Replay

- Replace logged ssrc with ssrc for payload type
- Replace logged sequence number with logged sequence number - starting logged sequence number + starting sequence number for ssrc
- Pop a cryptor for the payload type and encrypt the payload
  - If there are no cryptors left, don’t send and wait

Fixing headers (replay)



Demo

Conclusions

- Hooking is generally the best strategy, balancing time investment and functionality
- Stand alone clients and network interceptions are also options
- Tools like Frida can make hooking easy in some circumstances
- Otherwise binary modification is necessary

Conclusions

- Found many bugs with these techniques

https://bugs.chromium.org/p/project-zero/issues/list?can=2&q=label%3AFinder-natashenka

Conclusions

Questions

https://googleprojectzero.blogspot.com/

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