Reverse Engineering Outernet:
a look to the past and future

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Outline

Outline

What is Outernet?

- Startup company with goal of easing worldwide Internet access by broadcasting content from satellites
- Aims for almost worldwide coverage
- August 2014. Started broadcasting on Ku-band (11GHz) DTH satellites using DVB-S
- May 2016. Switched to narrowband broadcasts on L-band (1.5GHz) through 3 Inmarsat satellites (Americas, Europe/Africa, Asia/Pacific)
- January 2018. L-band service terminated
- Future narrowband Ku-band service. Currently some intermittent tests over North America

Data rates & receiving equipment

- Ku-band DVB-S
  - Typically 27.5Mbaud QPSK (or higher order PSK). Multiplex shared with TV channels and other services
  - 90kbps data service inside the multiplex
  - Spot beams. Regional coverage per beam
  - Parabolic dish, LNB, DVB-S set-top-box or dongle
- L-band single-service channel
  - 4.2kbaud BPSK. Only gives 15MB/day
  - Global beam. 1/3rd Earth coverage per satellite
  - Patch antenna, LNA, SDR dongle (RTL-SDR)
- Ku-band single-service channel
  - 30-100kbps service claimed
  - Typically spot beams
  - No dish claimed (maybe?), LNB, SDR dongle (RTL-SDR)

Outernet's "business" model

- Anyone can receive Outernet for free. Receiver software can be downloaded from Outernet's web site
- Most of the software is open-source, but the key components are closed-source and the signal coding and protocols are not public
- Outernet sells receiver hardware kits, but you can also make your own using off-the-shelf components
- Some people wonder how Outernet manages to make any money. Maybe they live off investors

Reverse engineering Outernet L-band service

- In October 2016 I reverse-engineered the L-band service almost completely
- This work was presented in the 33th Chaos Communication Congress in December 2016
- In January 2017, George Hopkins figured out the last missing details
- The L-band service is now completely documented and a fully functional open-source receiver is available
- Why reverse engineer Outernet?
  - A secret protocol and closed-source software don't serve well the goal of easing worldwide Internet access
  - Amateur Radio operators started playing with Outernet. Closed-source and secret protocols detrimental for Amateur Radio
- Things I knew before starting:
  - RF goes in, files come out. About 2kbps bitrate or 20MB of content per day
  - `outernet-linux-lband` closed-source software (Older version for Linux x86_64. Now everything is for ARM): `sdr100-1.0.4`, SDR modem for RTL-SDR; `ondd-2.2.0`, does everything else
  - IQ recordings by Scott Chapman K4KDR

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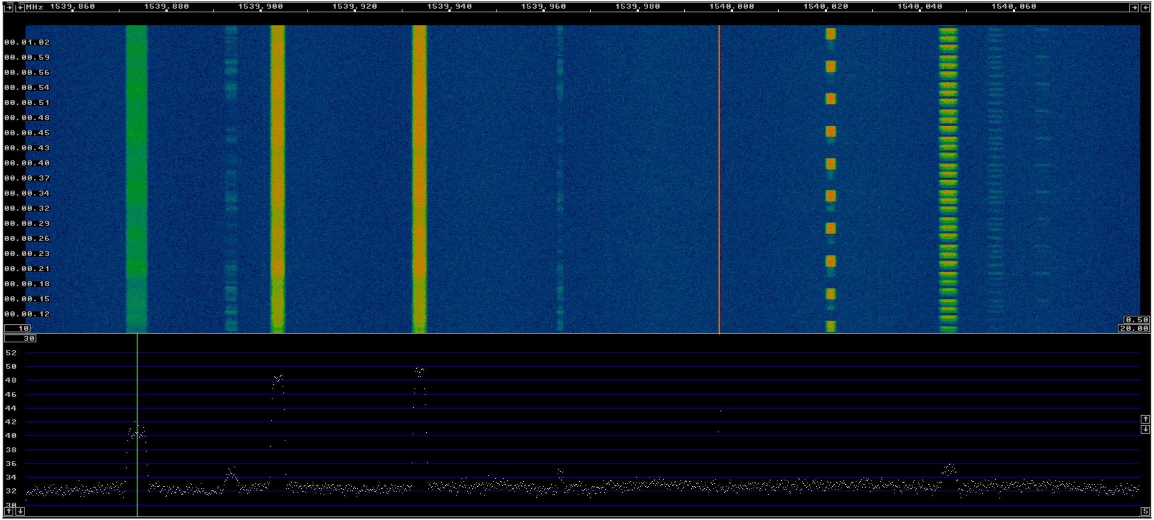
Waterfall in Linrad



Modulation

- 4.8kHz wide
- Looks like a hump in the noise floor
- “Any sufficiently advanced communication scheme is indistinguishable from noise” — Phil Karn KA9Q
- We suspect PSK modulation. BPSK and QPSK are good candidates
- We use GNU Radio for signal processing. First step: find out PSK order and baudrate

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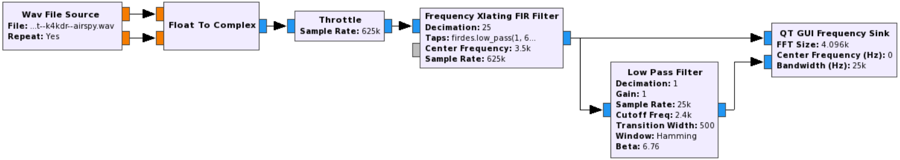
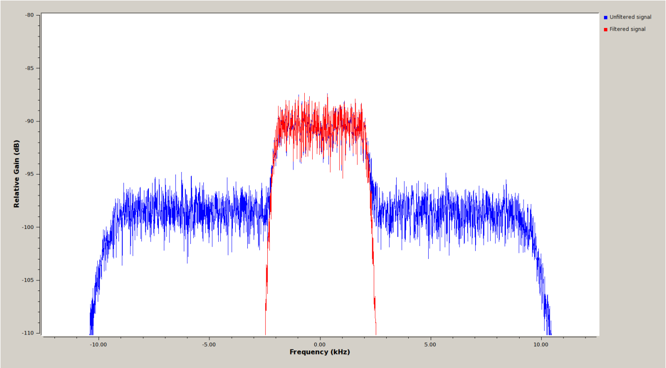
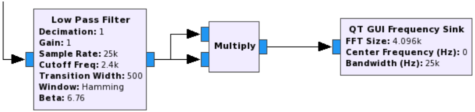
Reading from IQ wav file in GNU Radio

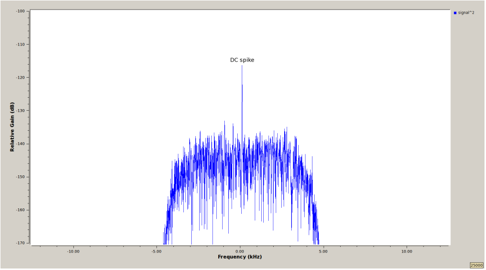




PSK order

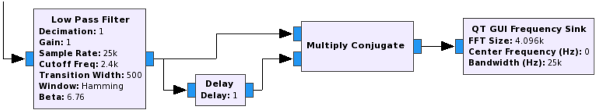
Raise the signal to integer powers

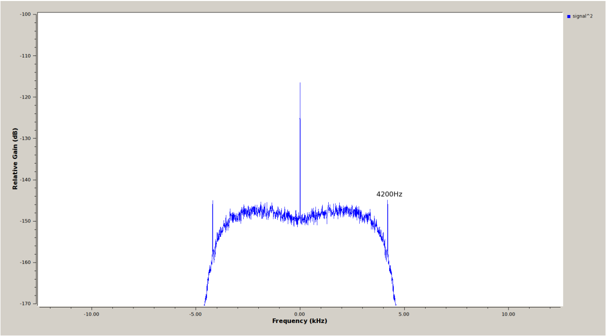




Power 2 of the signal has DC spike ⇒ BPSK
For QPSK, we would need to go to 4th power

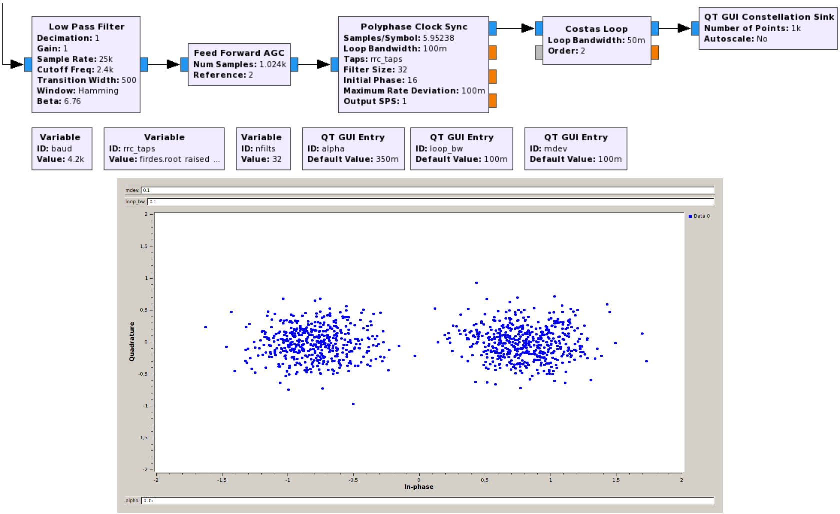
Cyclostationary analysis





Baudrate is 4200baud

BPSK demodulation



Coding

- Baudrate is 4200baud but bitrate is only about 2kbps
- We suspect $r = 1/2$ FEC in use
- Most popular choice: $r = 1/2, k = 7$ convolutional code with CCSDS polynomials
- We use Balint Seeber's AutoFEC to find FEC parameters
- "Standard" CCSDS convolutional code, but with the two polynomials swapped
- We use GNU Radio Viterbi decoder to decode FEC

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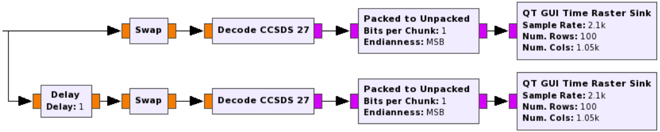
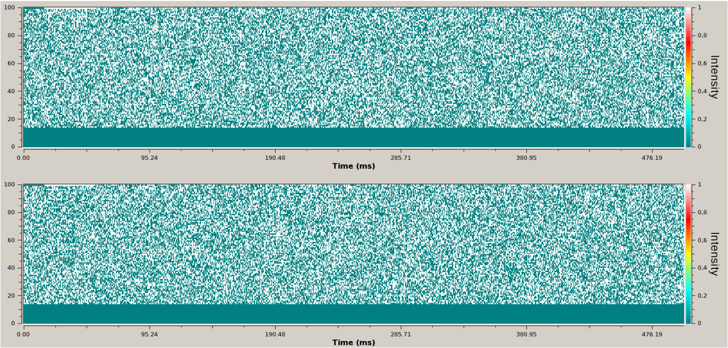
Viterbi decoding





Output looks random ⇒ we need a descrambler

Descrambler

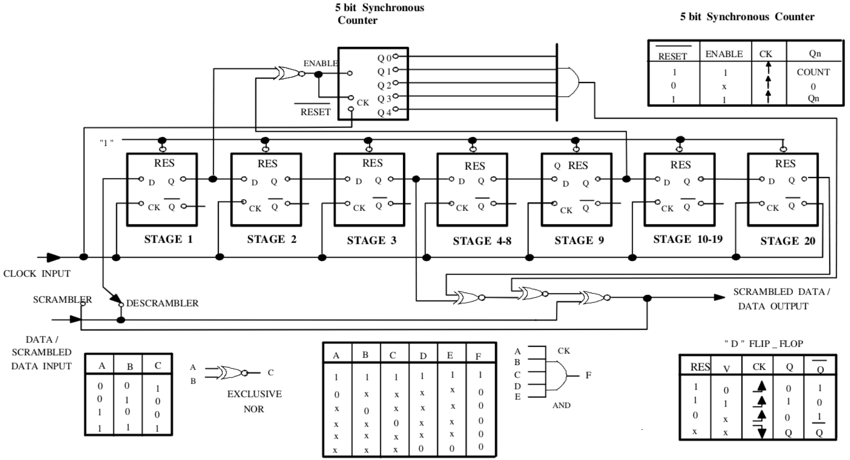
- The most popular descramblers I knew of didn't work
- Reverse engineer the assembler code for the descrambler in `sdr100`

```
0000000000406980 <descrambler308>:
  406980:       85 f6                   test   %esi,%esi
  406982:       75 7c                   jne    406a00 <descrambler308+0x80>
  406984:       8b 15 c2 7f 20 00       mov    0x207fc2(%rip),%edx        # 60e94c <shft_state.1868>
  40698a:       8b 35 b8 7f 20 00       mov    0x207fb8(%rip),%esi        # 60e948 <advst_cntr.1862>
  406990:       89 d0                   mov    %edx,%eax
  406992:       41 89 d0                mov    %edx,%r8d
  406995:       c1 e8 11                shr    $0x11,%eax
  406998:       31 d0                   xor    %edx,%eax
  40699a:       83 e0 01                and    $0x1,%eax
  40699d:       89 c1                   mov    %eax,%ecx
  40699f:       31 c0                   xor    %eax,%eax
  4069a1:       83 fe 1f                cmp    $0x1f,%esi
  4069a4:       0f 94 c0                sete   %al
  4069a7:       41 c1 e8 13             shr    $0x13,%r8d
  4069ab:       89 05 8f 7f 20 00       mov    %eax,0x207f8f(%rip)        # 60e940 <as_det.1865>
  4069b1:       31 c8                   xor    %ecx,%eax
  4069b3:       89 d1                   mov    %edx,%ecx
  4069b5:       31 f8                   xor    %edi,%eax
  4069b7:       c1 e9 0b                shr    $0xb,%ecx
  4069ba:       83 e0 01                and    $0x1,%eax
  4069bd:       44 31 c1                xor    %r8d,%ecx
  4069c0:       83 f0 01                xor    $0x1,%eax
  4069c3:       83 e1 01                and    $0x1,%ecx
  4069c6:       89 05 78 7f 20 00       mov    %eax,0x207f78(%rip)        # 60e944 <outbit.1863>
  4069cc:       74 22                   je     4069f0 <descrambler308+0x70>
  4069ce:       c7 05 70 7f 20 00 00    movl   $0x0,0x207f70(%rip)        # 60e948 <advst_cntr.1862>
  4069d5:       00 00 00
  4069d8:       d1 ea                   shr    %edx
  4069da:       85 ff                   test   %edi,%edi
  4069dc:       8d 8a 00 00 08 00       lea    0x80000(%rdx),%ecx
  4069e2:       0f 45 d1                cmovne %ecx,%edx
  4069e5:       89 15 61 7f 20 00       mov    %edx,0x207f61(%rip)        # 60e94c <shft_state.1868>
  4069eb:       c3                      retq
  4069ec:       0f 1f 40 00             nopl   0x0(%rax)
  4069f0:       83 c6 01                add    $0x1,%esi
  4069f3:       83 e6 1f                and    $0x1f,%esi
  4069f6:       89 35 4c 7f 20 00       mov    %esi,0x207f4c(%rip)        # 60e948 <advst_cntr.1862>
  4069fc:       eb da                   jmp    4069d8 <descrambler308+0x58>
  4069fe:       66 90                   xchg   %ax,%ax
  406a00:       c7 05 42 7f 20 00 00    movl   $0x0,0x207f42(%rip)        # 60e94c <shft_state.1868>
  406a07:       00 00 00
  406a0a:       c7 05 34 7f 20 00 00    movl   $0x0,0x207f34(%rip)        # 60e948 <advst_cntr.1862>
  406a11:       00 00 00
  406a14:       31 c0                   xor    %eax,%eax
  406a16:       c7 05 24 7f 20 00 00    movl   $0x0,0x207f24(%rip)        # 60e944 <outbit.1863>
  406a1d:       00 00 00
  406a20:       c3                      retq
  406a21:       66 2e 0f 1f 84 00 00    nopw   %cs:0x0(%rax,%rax,1)
  406a28:       00 00 00
  406a2b:       0f 1f 44 00 00          nopl   0x0(%rax,%rax,1)
```

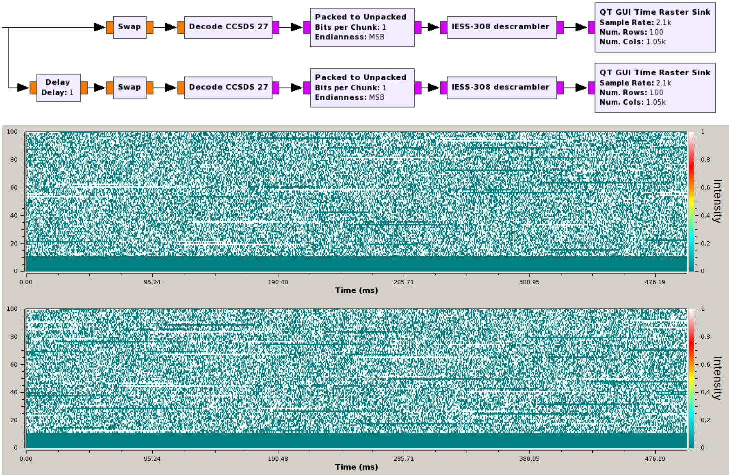
```c
uint32_t shft_state;
uint32_t advst_cntr;
uint32_t outbit;
uint32_t as_det;

uint32_t descrambler308(uint32_t inbit, uint32_t reset) {
  if (reset) {
    shft_state = 0;
    advst_cntr = 0;
    outbit = 0;

    return 0;
  }

  as_det = advst_cntr == 0x1f;

  outbit = ~(inbit ^ as_det ^ shft_state ^ (shft_state >> 17)) & 1;

  if (((shft_state >> 19) ^ (shft_state >> 11)) & 1) {
    advst_cntr = 0;
  }
  else {
    advst_cntr++;
    advst_cntr &= 0x1f;
  }

  shft_state >>= 1;
  if (inbit) {
    shft_state |= 1 << 19;
  }

  return outbit;
}
```

IESS-308 scrambler

It turns out the scrambler is V.35, used in the IESS-308 standard, very popular in GEO satellite comms, but mostly unheard of in Amateur LEO satellites



Descrambling

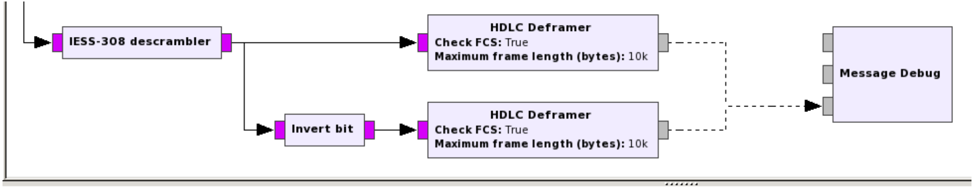


Now we can see some structure in the output

Framing

- Several functions in the `sdr100` binary have “HDLC” in them
- We suspect HDLC framing
- We use the HDLC deframer from `gr-satellites` (there’s also a stock deframer in GNU Radio)

HDLC deframing




```
***********************************
* MESSAGE DEBUG PRINT PDU VERBOSE *
()
pdu_length = 276
contents =
0000: ff ff ff ff ff ff 00 30 18 c1 dc a8 8f ff 01 04
0010: 3c 02 00 00 18 00 01 00 00 00 08 11 10 ba de e0
0020: bc 38 b4 34 e1 f9 74 73 92 f9 b8 41 52 db 20 ce
0030: a0 65 f5 c6 9b 66 0c c5 36 42 3c 66 fb 69 0e d8
0040: ca 2d fa 44 5a 57 74 8e 91 6b 98 34 45 51 3f e7
0050: c8 a6 08 69 f7 c5 67 71 cd b7 26 60 0a 03 cd 20
0060: 5d 49 45 88 bd a6 e9 89 87 86 25 3d 9e 83 9a e7
0070: fd 35 73 aa 4e 96 12 8d 1c 16 8f 0f 25 74 a2 12
0080: de bc 03 c9 47 57 5a 26 85 b2 a4 a8 be 4b 22 ce
0090: bd f7 e3 8a 9d 96 42 4a 25 7e c9 c3 be 64 ab 9d
00a0: b4 14 34 3a 24 4d 8a 40 1a 7e ad e8 0b d9 0e 0b
00b0: 8a a9 10 c2 c8 49 7c 69 4c a9 4e 65 53 e6 89 a4
00c0: aa 6b e8 7e ae 78 95 4b f8 96 68 05 17 15 8f 15
00d0: a2 79 0a 3d dd 52 37 86 fa 31 97 b9 d0 2b 1b 1e
00e0: 79 da 93 0c 02 81 77 3a 2e 35 80 10 74 0f 54 e3
00f0: 86 af cb c5 8b 38 64 78 de 09 37 9f 3d 3a 64 4e
0100: fe 86 21 7b 8c b1 55 05 5d fd 2a 4a 17 c1 37 69
0110: 5c d1 7b 1c
***********************************
```

Outline

Reverse engineering frames

- Techniques used:
  - Look at hex dumps of the frames
  - `ondd` usually gets frames from `sdr100` via Unix socket. Inject frames into `ondd` and see what happens
- Outernet uses custom network protocols $\Rightarrow$ I get to name them as I like!

A typical frame

```
0000: ff ff ff ff ff ff 00 30 18 c1 dc a8 8f ff 01 04
0010: 3c 02 00 00 18 00 01 00 00 00 08 11 10 e5 21 4b
0020: 48 2c e0 77 00 86 4d 14 06 3c 24 f7 30 e7 19 4c
0030: ed 60 d4 44 94 6a 4a 18 34 ad b2 b5 92 01 b7 87
0040: 06 ba 80 61 a5 87 06 80 f6 04 12 f6 d9 12 13 02
0050: 64 0b 68 94 21 36 01 ab af 01 50 d0 13 4b dc b6
0060: 92 90 6b f4 76 27 73 3d 91 f5 84 3d 75 d9 77 90
0070: d2 74 15 49 66 e5 9a 57 df df 72 28 32 48 97 ed
0080: 9a 46 6e 68 8e 72 b3 54 5f 52 ce f6 f5 de c1 fd
0090: e4 e6 f8 a2 bd bb bb 65 cf 9e d0 ed 80 1e ad 8c
00a0: 0c b8 59 28 41 cf 27 d3 cf a9 9e 28 06 8e c0 c8
00b0: 42 7a bd ea da ae 7e 41 ee 24 c2 f9 28 b7 35 f6
00c0: 8b 12 13 23 1f fb 0d 3e 32 49 b9 75 4b 31 d3 29
00d0: 11 c1 48 a2 3b d4 8b 40 e6 2c 69 02 59 f2 f8 c8
00e0: d2 ea aa ce 63 57 ed f7 25 42 8e 9b 21 d4 64 07
00f0: 89 59 d0 47 d6 7b c7 3c c7 11 2c 91 d3 ca b1 52
0100: ea ba be e3 00 39 fb be 6a 02 52 e3 8f ac ba 30
0110: b7 d1 c2 3f
```

A typical frame

```
0000: ff ff ff ff ff ff 00 30 18 c1 dc a8 8f ff 01 04
0010: 3c 02 00 00 18 00 01 00 00 00 08 11 10 e5 21 4b
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0030: ed 60 d4 44 94 6a 4a 18 34 ad b2 b5 92 01 b7 87
0040: 06 ba 80 61 a5 87 06 80 f6 04 12 f6 d9 12 13 02
0050: 64 0b 68 94 21 36 01 ab af 01 50 d0 13 4b dc b6
0060: 92 90 6b f4 76 27 73 3d 91 f5 84 3d 75 d9 77 90
0070: d2 74 15 49 66 e5 9a 57 df df 72 28 32 48 97 ed
0080: 9a 46 6e 68 8e 72 b3 54 5f 52 ce f6 f5 de c1 fd
0090: e4 e6 f8 a2 bd bb bb 65 cf 9e d0 ed 80 1e ad 8c
00a0: 0c b8 59 28 41 cf 27 d3 cf a9 9e 28 06 8e c0 c8
00b0: 42 7a bd ea da ae 7e 41 ee 24 c2 f9 28 b7 35 f6
00c0: 8b 12 13 23 1f fb 0d 3e 32 49 b9 75 4b 31 d3 29
00d0: 11 c1 48 a2 3b d4 8b 40 e6 2c 69 02 59 f2 f8 c8
00e0: d2 ea aa ce 63 57 ed f7 25 42 8e 9b 21 d4 64 07
00f0: 89 59 d0 47 d6 7b c7 3c c7 11 2c 91 d3 ca b1 52
0100: ea ba be e3 00 39 fb be 6a 02 52 e3 8f ac ba 30
0110: b7 d1 c2 3f
```

- Ethernet frame:
  - Broadcast destination
  - Source MAC
  - Custom ethertype
- Length: 276 bytes ⇒ aprox. 1 second over the air (this is Outernet's MTU)

L3 protocol: OP

- OP = "Outernet Protocol" (pun on IP)
- Handles fragmentation
- Packet order is preserved ⇒ fragmentation is very simple

```
0000: ff ff ff ff ff ff 00 30 18 c1 dc a8 8f ff 01 04
0010: 3c 02 00 00 18 00 01 00 00 00 08 11 10 e5 21 4b
.....................................................
```

- OP packet size
- Fragmentation `3c` = last fragment, `c3` = fragments remain
- Carousel ID (reverse engineered from `ondd` by George Hopkins)
- Fragment number of last fragment
- Fragment number of this fragment

L4 protocol: LDP

- LDP = "Lightweight Datagram Protocol" (pun on UDP)
- Datagram protocol. Has some sort of port or SID to identify services

```
0000: ff ff ff ff ff ff 00 30 18 c1 dc a8 8f ff 01 04
0010: 3c 02 00 00 18 00 01 00 00 00 08 11 10 e5 21 4b
...........................................
0110: b7 d1 c2 3f
```

- Type (port or SID) (`0x18` marks a file block)
- LDP packet size
- Checksum CRC32-MPEG2 (algorithm found by G. Hopkins)

Time service packets

- Time packet broadcast every minute
- Used to set the receiver clock (NTP not an option for receiver without internet access)

```
0000: ff ff ff ff ff ff 00 30 18 c1 dc a8 8f ff 00 1c
0010: 3c 00 00 00 81 00 00 18 01 04 6f 64 63 32 02 08
0020: 00 00 00 00 57 f6 94 20 48 3a ca 8d 00 00 00 00
0030: 00 00 00 00 00 00 00 00 00 00 00 00
```

- Variable record length structure
- Ethernet + OP + LDP header (sent to SID `0x81`)
- Record type `0x01` is Groundstation ID, `0x02` is Unix timestamp (G. Hopkins)
- Record length (found by G. Hopkins)
- ASCII for `odc2` (Outernet DataCasting 2) ⇒ Groundstation for Americas satellite
- Unix timestamp 06 Oct 2016 18:12:48
- LDP checksum
- Padding (not included in OP or LDP packet) ⇒ mTU (minimum transfer unit) = 46 bytes

File service overview

- Broadcasts one file at a time (could broadcast several simultaneosly)
- Splits each file into 242 byte blocks
- Uses LDPC codes to recover the file even if some blocks are not received
- Types of packets:
  - File announcement. Sent first. Basic info about file
  - File block (242 bytes of the file)
  - FEC block (242 bytes of parity check symbols from LDPC code)
- File blocks and FEC blocks are sent interleaved and in order (not necessary)

File announcement packets

- Large LDP packet (uses fragmentation)
- File info in ASCII XML
- Signed with X.509 certificate (to prevent spoofing?)

```
<?xml version="1.0" encoding="UTF-8"?>
<file>
  <id>2380</id>
  <path>opaks/dad7-Alt-right.html.tbz2</path>
  <hash>aed3e3b58193bdda9af9adb700972cb
        426ca26b336e36c2dfa0175b6e1deb4c8</hash>
  <size>109186</size>
  <block_size>242</block_size>
  <fec>ldpc:k=452,n=543,N1=2,seed=1000</fec>
</file>
```

- Hash is SHA256

File block packets

```
0000: ff ff ff ff ff ff 00 30 18 c1 dc a8 8f ff 01 04
0010: 3c 02 00 00 18 00 01 00 00 00 08 11 10 e5 21 4b
0020: 48 2c e0 77 00 86 4d 14 06 3c 24 f7 30 e7 19 4c
0030: ed 60 d4 44 94 6a 4a 18 34 ad b2 b5 92 01 b7 87
0040: 06 ba 80 61 a5 87 06 80 f6 04 12 f6 d9 12 13 02
0050: 64 0b 68 94 21 36 01 ab af 01 50 d0 13 4b dc b6
0060: 92 90 6b f4 76 27 73 3d 91 f5 84 3d 75 d9 77 90
0070: d2 74 15 49 66 e5 9a 57 df df 72 28 32 48 97 ed
0080: 9a 46 6e 68 8e 72 b3 54 5f 52 ce f6 f5 de c1 fd
0090: e4 e6 f8 a2 bd bb bb 65 cf 9e d0 ed 80 1e ad 8c
00a0: 0c b8 59 28 41 cf 27 d3 cf a9 9e 28 06 8e c0 c8
00b0: 42 7a bd ea da ae 7e 41 ee 24 c2 f9 28 b7 35 f6
00c0: 8b 12 13 23 1f fb 0d 3e 32 49 b9 75 4b 31 d3 29
00d0: 11 c1 48 a2 3b d4 8b 40 e6 2c 69 02 59 f2 f8 c8
00e0: d2 ea aa ce 63 57 ed f7 25 42 8e 9b 21 d4 64 07
00f0: 89 59 d0 47 d6 7b c7 3c c7 11 2c 91 d3 ca b1 52
0100: ea ba be e3 00 39 fb be 6a 02 52 e3 8f ac ba 30
0110: b7 d1 c2 3f
```

- We return to our typical frame
- Ethernet + OP + LDP header
- File ID
- Block number
- Block contents (242 bytes)
- LDP checksum
- FEC blocks have the same structure (and different SID)

Application level FEC (due to George Hopkins)

- Forward Error Correction codes working at the "application level" to restore missing or corrupted information upon reception
- Usually work as erasure codes (recover missing data at known positions)
- Fits nicely with Outernet link, where some packets may be lost, but received packets are error-free
- Outernet uses two application level FEC systems:
  - Erasure code to recover lost OP fragments
  - LDPC code to recover lost file blocks

Erasure code for OP fragments

- A (trivial) case of Reed-Solomon (1960), “rediscovered” and popularized by Luigi Rizzo (1997). Implemented in zfec. Credit should be given to Reed and Solomon
- For each packet with k fragments ($k \geq 2$), 3 extra fragments with parity check symbols are sents after the k fragments
- The packet can be completely recovered even if up to 3 fragments are lost from this set of $k + 3$ fragments
- Quite important for file annoucements ($k = 6$ or 7 typically). If you lose the announcement, you probably lose the whole file
- Parity check symbol fragments are marked with `0x69` as fragmentation field and numbered from `00` to `02` using the fragment number fields.

LDPC code for file blocks

- Essentially, the LDPC code follows RFC5170, which describes pseudorandomly-generated LDPC erasure codes for use as application level FEC
- Bistromath and I already suspected in October 2016 that RFC5170 was used, but all my attempts at FEC decoding failed
- The Lehmer/Park-Miller PRNG is used to generate the parity check matrix for the LDPC code:

$$x_{n+1} = 7^5 x_n \mod 2^{31} - 1.$$

- But x_n has to be brought down to the range $[0, m]$. As you may know, the least significant bits are less random, so division instead of modulo should be used. The RFC reminds us of this.
- However, Outernet used modulo (FAIL!), so no wonder that my decoding attempts failed

- FEC blocks are sent between the file blocks, using SID `0xff` and file ID and block number as in file blocks
- A file of s bytes is sent in $k = \lceil s/242 \rceil$ blocks. An (n, k) LDPC code is selected to get a rate $r = k/n$ of approximately $5/6$, so $n = \lceil 6k/5 \rceil$, and $n - k$ FEC blocks are used

What do we have now?

- Lots of documentation about Outernet protocols:
  `http://destevez.net/tag/outernet/`
- GNU Radio receiver. Uses an SDR to get Outernet frames. Realtime output by UDP socket and KISS file recording:
  `https://github.com/daniestevez/gr-outernet`
- Python implementation of the file transfer protocol. Can get frames in realtime by UDP socket or from KISS file recording:
  `https://github.com/daniestevez/free-outernet`

free-outernet demo

Outline

Outernet groundstation satellite modem

- X.509 certificates for file announcements use as CN `odc2.outernet.is`, `odc3.outernet.is`, etc.
- Let's go to `http://odc2.outernet.is/`!
- The HTTP port is blocked now, but previously it led to the login page of the satellite modem (huge security flaw)
- It's the M7 modem from Datum Systems
- Lots of documentation available for you modem fans!

Specifications	
Operating Modes	TX and RX Continuous (SCPC) *Flex*LDPC, Flexible Block and Code Rates, Low Latency Advanced TPC and Industry Compatible Std and Custom Async Low Overhead Channels, AUPC Remote Modem Control Channel IP, Ethernet, Dual G.703/E1 (D&I), Serial, HSSI Opt Plug-in I/O Selections (Up to 2 per M7 Unit)
Data Rate Range	1.2 kbps to 59.04 Mbps, (1 bps steps)
Symbol Rate Range	2400 sps to 14.76 Msps (1 sps steps)
FrequencyTuning Range	M7 50-180 MHz, M7L 950-2150 MHz (1 Hz steps)
Modulation Types	BPSK,QPSK,OQPSK,8PSK/QAM,16QAM
FEC Options	None, Viterbi, TCM, Reed-Solomon, *Flex*LDPC TPC 4k and TPC 16k (Opt Plug-in HW)
Advanced *Flex*LDPC	Block Sizes 256,512,1k,2k,4k,8k,16k Rates 1/2,2/3,3/4,14/17,7/8,10/11,16/17
Turbo Product Code	TPC-4k 21/44, 1/2, 3/4, 7/8, 0.950 TPC-16k 1/2, 3/4, 7/8, 0.453, 0.922
Viterbi	1/2, 3/4, 7/8 (k=7), Trellis 2/3
Reed Solomon	Selectable N & K, IESS 308/309/310
Scrambler/Descrambler	IBS, V.35, IESS, TPC, RS, LDPC, EFD

FlexLDPC™	Typical Eb/No for 1E-8 BER				Delay @64kbps
	QPSK	8PSK	8QAM	16QAM	
LDPC-1/2 - 2k	2.04 dB	n/a	3.80 dB	4.48 dB	49.6 ms
LDPC-1/2-4k	1.73 dB	n/a	3.44 dB	4.16 dB	98.0 ms
LDPC-1/2-8k	1.52 dB	n/a	3.19 dB	3.92 dB	195.0 ms
LDPC-1/2-16k	1.38 dB	n/a	3.04 dB	3.76 dB	388.6 ms
LDPC-2/3-2k	2.77 dB	4.88 dB	4.68 dB	5.85 dB	44.4 ms
LDPC-2/3-4k	2.46 dB	4.53 dB	4.36 dB	5.46 dB	87.5 ms
LDPC-2/3-8k	2.23 dB	4.28 dB	4.09 dB	5.19 dB	173.7 ms
LDPC-2/3-16k	2.09 dB	4.14 dB	3.91 dB	5.01 dB	346.1 ms
LDPC-3/4-2k	3.52 dB	5.97 dB	5.51 dB	6.78 dB	41.9 ms
LDPC-3/4-4k	3.14 dB	5.56 dB	5.11 dB	6.37 dB	82.4 ms
LDPC-3/4-8k	2.89 dB	5.27 dB	4.83 dB	6.07 dB	163.1 ms
LDPC-3/4-16k	2.72 dB	5.07 dB	4.63 dB	5.87 dB	325.0 ms
LDPC-7/8-2k	4.96 dB	7.89 dB	6.98 dB	8.48 dB	38.1 ms
LDPC-7/8-4k	4.32 dB	7.21 dB	6.40 dB	7.84 dB	74.6 ms
LDPC-7/8-8k	4.00 dB	6.86 dB	6.05 dB	7.51 dB	147.3 ms
LDPC-7/8-16k	3.90 dB	6.66 dB	5.87 dB	7.32 dB	293.6 ms
LDPC-10/11-2k	5.63 dB	8.73 dB	7.68 dB	9.37 dB	37.0 ms
LDPC-10/11-4k	5.00 dB	7.99 dB	7.02 dB	8.63 dB	72.3 ms
LDPC-10/11-8k	4.58 dB	7.51 dB	6.60 dB	8.18 dB	143.0 ms
LDPC-10/11-16k	4.40 dB	7.33 dB	6.35 dB	7.95 dB	284.5 ms

Guaranteed Eb/No is 0.2 dB > Typical

Modulator

Demodulator	
Input Acquisition Range	±100 Hz to ±3 MHz, 1 Hz Steps
Minimum Input Level	10 × Log(Symbol Rate) - 125 = Lvl (dBm)
Maximum Input Level	10 × Log(Symbol Rate) - 80 = Lvl (dBm)
Maximum IF Input Power Density	+20 dBc/Hz
Maximum Total Power	+10 dBm
Receive Acquisition Time	Typical 71 ms at 64 kbps, QPSK
Input Impedance	IF 50 or 75 Ohms BNC (User Selectable) L-Band 50 Ohms SMA
Input Return Loss	IF > 20 dB, L-Band > 16dB
Input Phase Noise	> Intelsat by 6 dB typical, 4 dB min
Demod Roll-Off Factor %	5, 8, 10, 15, 20, 25, 30, 35, 40 (%)

Smart Carrier Cancelling	
Delay Range	0 to 320 msec
Acquisition Time	< 30 Sec for Full Delay Sweep
Power Spectral Density	Ratio: +/- 10 dB: Symbol Rate Ratio: +/- 30% of Symbol Rate Frequency Offset: +/- 12.5% of Symbol Rate
Eb/No Degradation	PSD Ratio 0 dB BPSK/QPSK/OQPSK: 0.2 dB 8PSK/8QAM: 0.3 dB 16QAM: 0.5 dB

Interface Options: (Choose Up to Two Per Modem)

Serial Data Interface (S7)	
Main Interface Modes	Sync RS-232,449,V.35,EIA-530 (DB-25)
Internal Clock (ST) Accuracy	±1E-12, (±1 part per Trillion)
Doppler Buffer Depth	4 Bits to 524,284 Bits, 1 Bit Steps
ESC Overhead I/O Modes	Async RS-232,RS-485 (DB-25)
Adv Mux ESC OH Data Rate	Disabled, 300 bps to 3.5 Mbps, 1 bps Steps
Adv Mux (MCC) OH Data Rate	Disabled, 300 to 29.52 Mbps, 1 bps Steps
ESC Remote Signaling I/O's	Form C (Qty 2)

Advanced IP Interface (I7)	
Adv Ethernet IP Interface	10/100 BaseT, Gigabit Ethernet (RJ-45)
Operating System	Debian Linux Operating System
Operating Modes	Bridge and Vyatta Router
Packets Per Second	70,000 PPS
Network Protocols:	See Specification

Express Ethernet Interface (E7)	
Express Ethernet Ports	4Ports (RJ-45), 1 Port SFP
4 Port Interface	10/100 BaseT, Gigabit Ethernet (RJ-45)
SFP Port	Optional Gigabit or Optiuc Fiber
Ethernet Protocol	Layer 2 Swtched Bridge Only
Features	QoS and VLAN Selectable

Dual G.703/E1 Interface (G7)	
G.703 E1 Physical Inputs	Dual Bal Inputs on (RJ-48), UnBal Out

Groundstation geolocation

- Geolocate the `odc?.outernet.is` IPs
- `odc2.outernet.is` Americas 216.129.171.61 $\Rightarrow$ Toronto
- `odc3.outernet.is` Europe/Africa 212.165.126.66 $\Rightarrow$ Amsterdam
- `odc4.outernet.is` Asia/Pacific 123.100.88.137 $\Rightarrow$ Ketu Bay, New Zealand
- These are most likely located in large Inmarsat groundstation facilities

Actual data throughput

- Outernet stated about 20MB of content per day
- Is this true?
- 242 byte blocks sent inside 272 byte Ethernet frames $\Rightarrow$ 12% overhead for headers
- All but the smallest files use LDPC codes with a rate of about $5/6$ $\Rightarrow$ 20% overhead for FEC
- Total overhead of 30%
- Bitrate is 2.1kbps (At most. Should account for HDLC bit-stuffing)
- This only gives 15.14MB of content per day

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Outline

What can we expect?

- The network protocols need not change. Maybe free-outernet can still be used without modifications
- The modulation and coding will most likely change
- Need to look at the RF signal with fresh eyes once (and if) it goes live
- In the meantime, an example Ku-band single-service channel: Blockstream satellite
  - Bitcoin blockchain broadcast over Ku-band geostationary satellites
  - GNU Radio receiver `https://github.com/blockstream/satellite`
  - 156kbaud QPSK
  - Barker codes for preamble synchronization
  - Turbo codes for FEC
  - G3RUH scrambling and HDLC framing
- Or maybe something completely crazy and different:
  - 14 February. LoRA tests through SES-2 by Outernet at 11.9GHz.
  - 30kbps, received with LNB or custom patch antenna.
  - Claimed that LoRA is used to fight co-channel interference.
  - Maybe not a good idea. It seems they don't understand spread-spectrum properly.

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Thanks for your attention!