Isode

Analysis of OTA Measurements

Jim Peters

Isode Ltd

11/09/2014

Overview

Motivation for tests

Testing and the test results

Analyses based on results

Isode

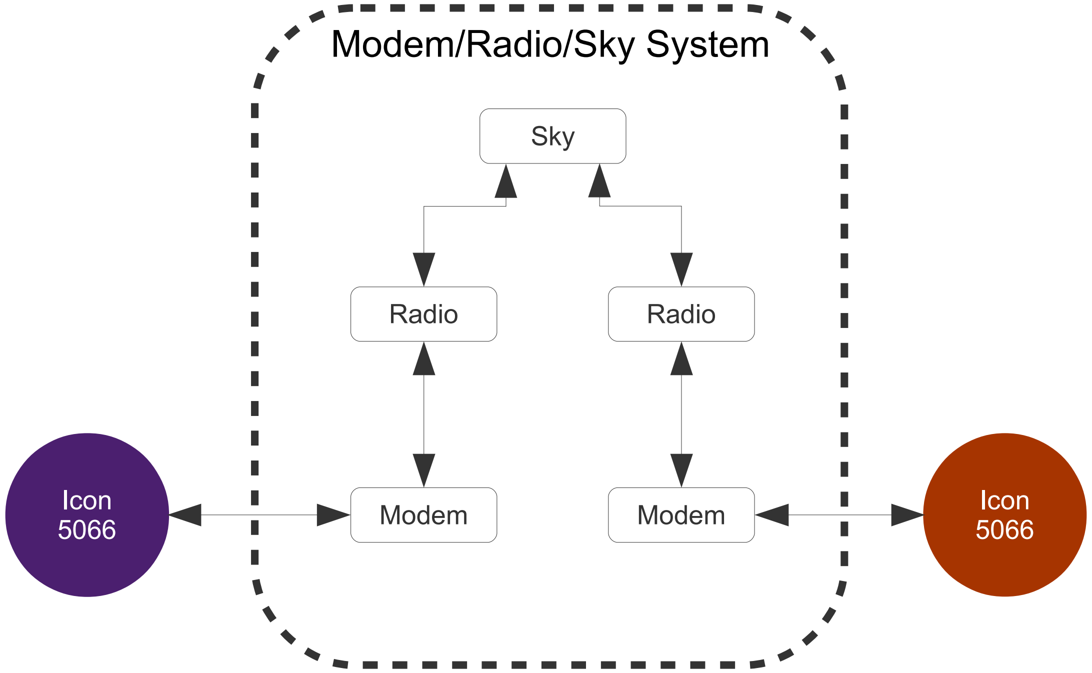
HF Radio from the STANAG 5066 perspective

Isode is looking at the subject of HF Radio from the perspective of STANAG 5066.

We're interested in how the whole system of modems/radio/sky affects our data stream, and how we can adjust to changing conditions:

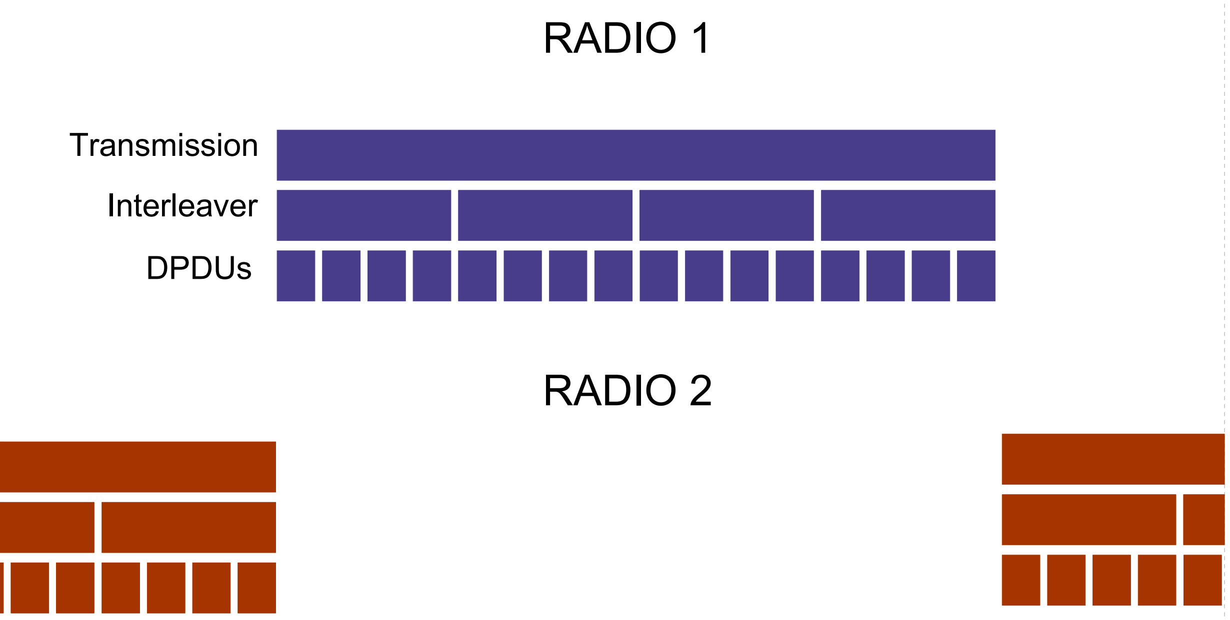
- Through adaptation of the data stream within protocol, and
- Through data rate change.

In some sense the Modem-Radio-Sky system is like a black box where we have only limited information about what is going on inside it.



Isode

Illustration of scales



From the perspective of 5066, there are various different scales that we are concerned with:

- DPDU length: up to 3s for the faster 4539 waveforms, up to 70ms for the very fastest WBHF waveforms
- Interleaver length: up to about 10s
- Transmission length: up to about 130s

Note:

- There is little point in making the interleaver shorter than the DPDU, unless optimising for latency on a very short transmission.
- DPDU size is the unit of loss at the 5066 level
- Interleaver size is the unit of loss at the modem level (although with a transition zone of partial failure)

Isode

Approximate relative scales

10s 130s 260s

Variations absorbed by interleaver, handled by modem	Variations knock out certain DPDUs within transmission	Some transmissions partly go through, others completely lost, others untouched	Variations longer-lasting
Switch to lower BPS	Retransmit DPDUs, maybe duplicate retransmissions	Retransmit DPDUs, NO duplicate retransmissions	Switch to lower BPS

Interleaver Length — Transmission Length — Turnaround Length

Isode

The different scales of the variations on the channel cause different problems and have to be dealt with differently.

- Variations shorter than the interleaver length are absorbed by the interleaver. If they increase too much, then bit errors are scattered over the whole interleaver length. These variations can be considered like a negative offset on the SNR. If they remain consistent, then we have to back off the data rate.
- Variations shorter than the transmission length will knock out certain interleaver blocks within each transmission. The DPDUs within those blocks have to be retransmitted. In simulation, it was found that a small percentage of DPDUs may fail several times in a row, which blocks data streams and increases latency as well as holding the window wide open. You can imagine this as the long tail of stragglers in a race. We need to give those stragglers extra help to keep up or otherwise our latency and window size suffer. Duplicate DPDU retransmissions within the same transmission length can help to reduce that problem.
- Variations longer than the transmission length may leave some transmissions untouched, knock out others completely, or partly damage others. Duplicate retransmissions are less helpful when there is a good chance of a whole transmission getting through.
- Variations much longer the turnaround length are on the scale that we can adapt to using a data-rate-change algorithm.

So we were interested in understanding what kinds of scales of variations we need to deal with. Randy Nelson and his team at Rockwell-Collins kindly ran some OTA tests for us to help us understand some of the patterns.

Isode

Test Details

- Tests kindly performed by Bradley Butikofer from Randy Nelson's team at Rockwell Collins

- Run over mid-latitude channel between Cedar Rapids and Las Cruces
  - 3 kHz, 12 kHz and 24 kHz bandwidths
  - STANAG 4539 and WBHF (110C-D)
  - Rockwell Collins RT-4800 Modems
  - Isode's hftool utility to drive modems over TCP/IP

Isode

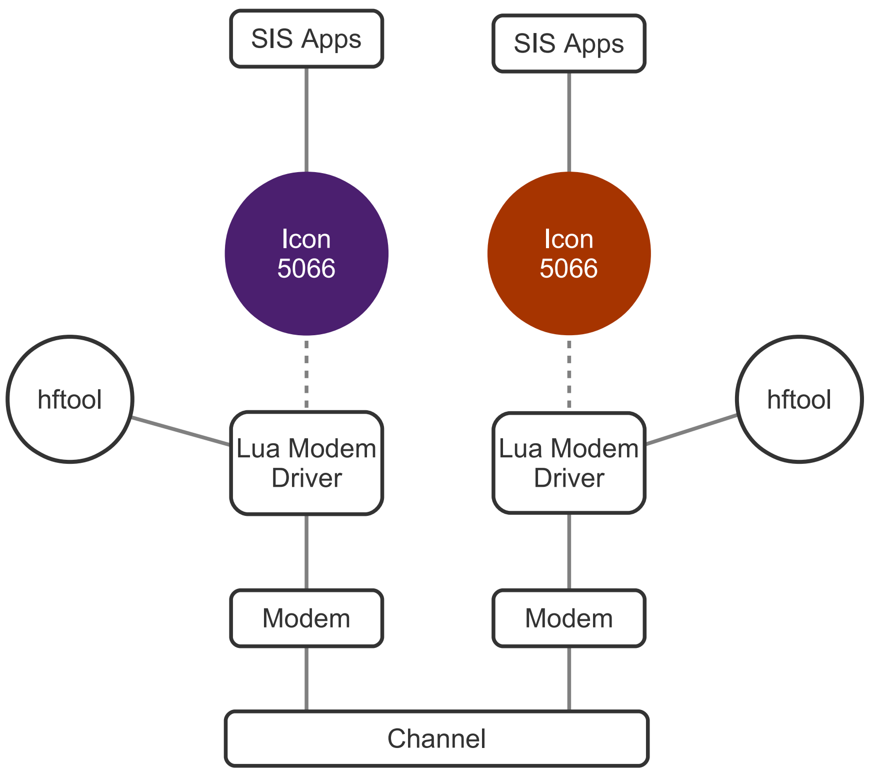
Testing lower layers with 'hftool'

'hftool' is a command-line utility that we wrote to test the layers immediately below the 5066 server independently from the 5066 server.

It tests the Lua modem drivers, the modems, and whatever channel simulation or live radio channel appears between the modems.

One of the tests supported by 'hftool' is the OTA test:

- The sending side transmists known data for a period of time, and
- The receiving side analyses and records all the data received



Isode

OTA bit error dump

```
**START 2873948 (analysis dump of 2873948 received bytes)
*   ::
*390880  --------------------------4-------------------------------------------
*   ::
*651140  --------------------------------------34724566415533444534354643334452
*651210  5635244476355646464415444531-----------------------------------44453--
*651280  --------------------------14347634651---------------------------------
*651350  -------------------464355251--------445635235423----------------------
*651420  ---------------------------------------------------356341-------------
*651490  --------------------------------1452--44846625342633-----3541---------
*   ::
*651630  -3325423-----------343362-----------------------------------------1734
*651700  44326343457433-------35346562643443453453563237432-------3464384264542
*651770  5534523655643---------------------------------------------------------
*   ::
*651910  -------------------1335426542-----------------------------------------
*651980  ----------------------244-------------------------------------------34
*652050  3446633336341---------------3432465331--------------------------------
*652120  --------------331545653654414253653325571572443335432---------------44
*652190  316382544431------------------------------1543532---------------342436
*652260  66547231---------------------------------------------------------14516
*652330  341------------142543616454334542423------5331---------------------145
*652400  63546334554-----------------------------------------------------------
*   ::
*652610  1532-----------------2455431----------------343521---------13---------
*652680  -----------------------------------431----------1443443366544564625553
*652750  154454316435533564244---------------145341-----------2246346433-------
*652820  --------------------3344572455662421---------143557645325457163455331-
*652890  ------------3222641-------------------------46241-----1735663344438245
*652960  256354446434443443--------------------334462471824244736331-----------
*653030  ---------------------------------------4166646653445515743473333453531
*653100  ----------------------------3465431-----------------------352754346325
*653170  5463753544423-------------------36344652456324374---------------------
*653240  ------------------------------------354335545544456535424555-----353--
*653310  -----------------------------------------------2433426454634367245431-
*   ::
*653450  ----------------------------1341-----------332671---------------------
*653520  -------------------35444425442442533343442653352-----4451645465455334-
*653590  -------4441-------------4563442-------------------------------------34
*653660  356343------------------3434552---------------------------------------
*653730  -------------1243444473525333-----------------14523264453257232-------
*653800  ----------------------------------------------146444335---------------
*653870  --------------------------------------------------15634---------------
```

OTA valid span dump

```
*SENT-LEN-EST 2873948
*SENT-VALID-SPANS 0-390906 390907-651178 651238-651273 651278-651306 651317-651369
*SENT-VALID-SPANS 651398-651471 651477-651522 651551-651631 651638-651649
*SENT-VALID-SPANS 651655-651696 651783-651929 651939-652002 652005-652048
*SENT-VALID-SPANS 652063-652078 652088-652134 652173-652188 652202-652232
*SENT-VALID-SPANS 652239-652254 652268-652325 652333-652345 652376-652397
*SENT-VALID-SPANS 652411-652610 652614-652631 652638-652654 652671-652715
*SENT-VALID-SPANS 652718-652728 652771-652786 652792-652803 652813-652840
*SENT-VALID-SPANS 652889-652902 652909-652934 652978-652998 653019-653069
*SENT-VALID-SPANS 653100-653128 653135-653158 653183-653202 653219-653276
*SENT-VALID-SPANS 653308-653357 653379-653478 653482-653493 653499-653539
*SENT-VALID-SPANS 653601-653614 653621-653658 653666-653684 653691-653743
*SENT-VALID-SPANS 653759-653776 653793-653846 653855-653920 653925-653956
*SENT-VALID-SPANS 654019-654103 654104-654127 654155-654180 654188-654219
*SENT-VALID-SPANS 654233-654328 654381-654426 654428-654450 654469-654493
*SENT-VALID-SPANS 654498-654512 654532-654590 654604-654632 654666-654676
*SENT-VALID-SPANS 654694-654706 654728-654754 654773-654787 654810-654827
*SENT-VALID-SPANS 654862-654886 654904-654945 654951-654997 655031-655134
*SENT-VALID-SPANS 655158-655191 655206-655293 655340-655410 655447-655478
*SENT-VALID-SPANS 655483-655550 655557-655596 655601-655625 655642-655674
*SENT-VALID-SPANS 655698-655732 655742-655806 655824-655865 655884-655918
*SENT-VALID-SPANS 655920-655964 655968-655992 656053-656064 656237-656254
*SENT-VALID-SPANS 656281-656293 656297-656337 656349-656376 656459-656471
*SENT-VALID-SPANS 656485-656503 656517-656550 656564-656574 656679-656691
*SENT-VALID-SPANS 656782-656797 656819-656833 656888-656915 657038-657069
*SENT-VALID-SPANS 657090-657101 657107-657159 657290-657304 657379-657402
*SENT-VALID-SPANS 657438-657471 657495-657507 657600-657631 657804-657824
*SENT-VALID-SPANS 657886-657910 658112-658124 658139-658177 658190-658218
*SENT-VALID-SPANS 658250-658267 658412-658426 658497-658521 658530-658541
*SENT-VALID-SPANS 658546-658557 658717-658729 658734-658764 658775-658789
*SENT-VALID-SPANS 658797-658825 658839-658855 658960-658998 659003-659015
*SENT-VALID-SPANS 659326-659383 659408-659442 659537-659552 659556-659579
*SENT-VALID-SPANS 659582-659615 659898-659908 659954-659978 659986-660008
*SENT-VALID-SPANS 660054-660067 660164-660210 660257-660271 660336-660356
*SENT-VALID-SPANS 660456-660468 660594-660614 660628-660651 660858-660873
*SENT-VALID-SPANS 661081-661104 661148-661176 661211-661228 661246-661290
*SENT-VALID-SPANS 661423-661478 661496-661527 661550-661606 661755-661774
*SENT-VALID-SPANS 661781-661794 661796-661818 661863-661911 661933-661952
*SENT-VALID-SPANS 661957-661973 662034-662050 662065-662085 662120-662148
*SENT-VALID-SPANS 662162-662208 662214-662225 662384-662421 662427-662452
*SENT-VALID-SPANS 662472-662510 662535-662591 662594-662620 662666-662695
*SENT-VALID-SPANS 662731-662758 662894-662904 662911-662928 662984-663042
*SENT-VALID-SPANS 663053-663075 663087-663102 663111-663122 663141-663189
```

OTA channel quality information dump

```
**QUALITY 14:40:01.221 snr=25
**QUALITY 14:40:01.736 snr=25
**QUALITY 14:40:02.251 snr=26
**QUALITY 14:40:02.765 snr=26
**QUALITY 14:40:03.280 snr=27
**QUALITY 14:40:03.795 snr=27
**QUALITY 14:40:04.310 snr=29
**QUALITY 14:40:04.825 snr=29
**QUALITY 14:40:05.339 snr=30
**QUALITY 14:40:05.839 snr=30
**QUALITY 14:40:06.353 snr=29
**QUALITY 14:40:06.868 snr=29
**QUALITY 14:40:07.383 snr=31
**QUALITY 14:40:07.882 snr=31
**QUALITY 14:40:08.397 snr=30
**QUALITY 14:40:08.896 snr=30
**QUALITY 14:40:09.411 snr=32
**QUALITY 14:40:09.926 snr=32
**QUALITY 14:40:10.441 snr=31
**QUALITY 14:40:10.955 snr=31
**QUALITY 14:40:11.470 snr=33
**QUALITY 14:40:11.969 snr=33
**QUALITY 14:40:12.484 snr=33
**QUALITY 14:40:12.983 snr=33
**QUALITY 14:40:13.498 snr=33
**QUALITY 14:40:14.013 snr=33
**QUALITY 14:40:14.512 snr=33
**QUALITY 14:40:15.027 snr=33
**QUALITY 14:40:15.542 snr=32
**QUALITY 14:40:16.041 snr=32
**QUALITY 14:40:16.556 snr=32
**QUALITY 14:40:17.071 snr=32
**QUALITY 14:40:17.585 snr=34
**QUALITY 14:40:18.085 snr=34
**QUALITY 14:40:18.599 snr=34
**QUALITY 14:40:19.114 snr=34
**QUALITY 14:40:19.613 snr=32
**QUALITY 14:40:20.128 snr=32
**QUALITY 14:40:20.643 snr=33
**QUALITY 14:40:21.142 snr=33
**QUALITY 14:40:21.657 snr=33
**QUALITY 14:40:22.172 snr=33
**QUALITY 14:40:22.671 snr=33
```

The form of the known data allows the receiving side to synchronize even in the face of bit errors and so it can detect inserted/dropped bytes.

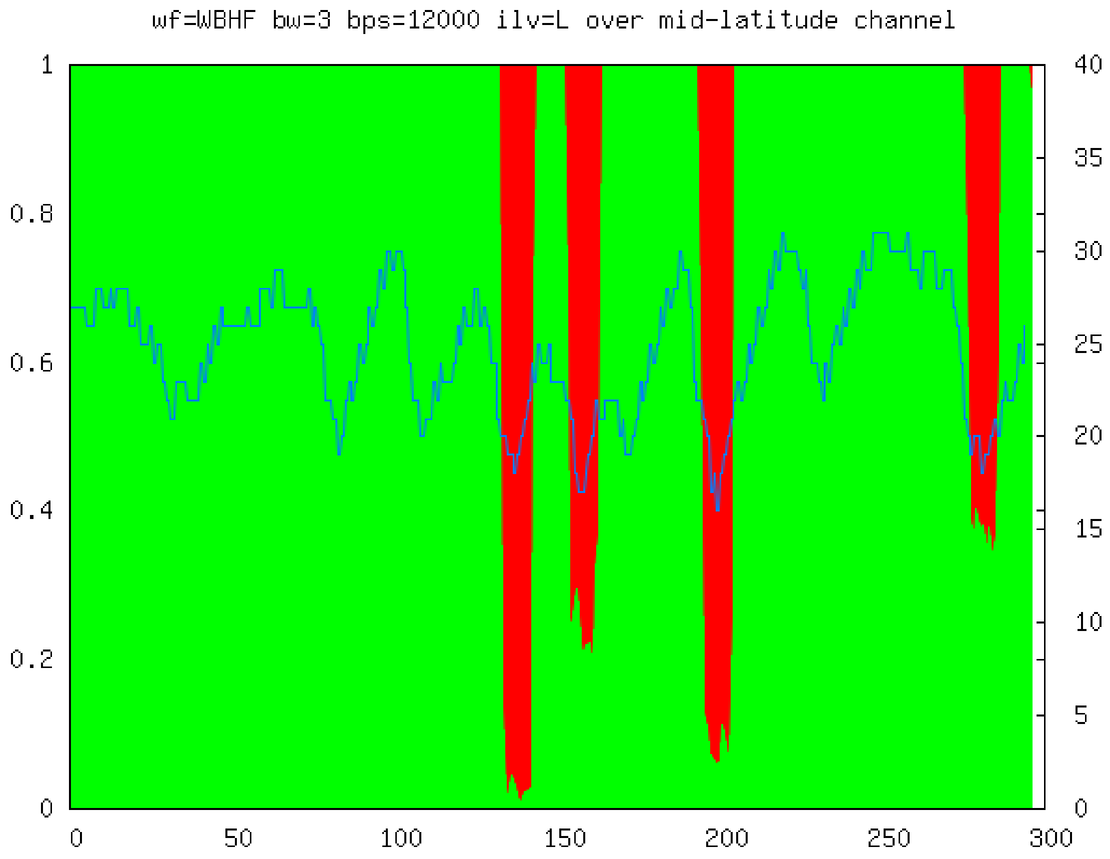
The output contains a dump of the number of bit errors for each byte, plus a list of the spans of valid bytes received, and a dump of all the channel quality information obtained from the modem by the modem driver, which usually includes SNR, but might also include multipath information and detected BPS and interleaver details.

We can plot the SNR and proportion of valid data received to get an idea of what is going on.

Isode

OTA example 1

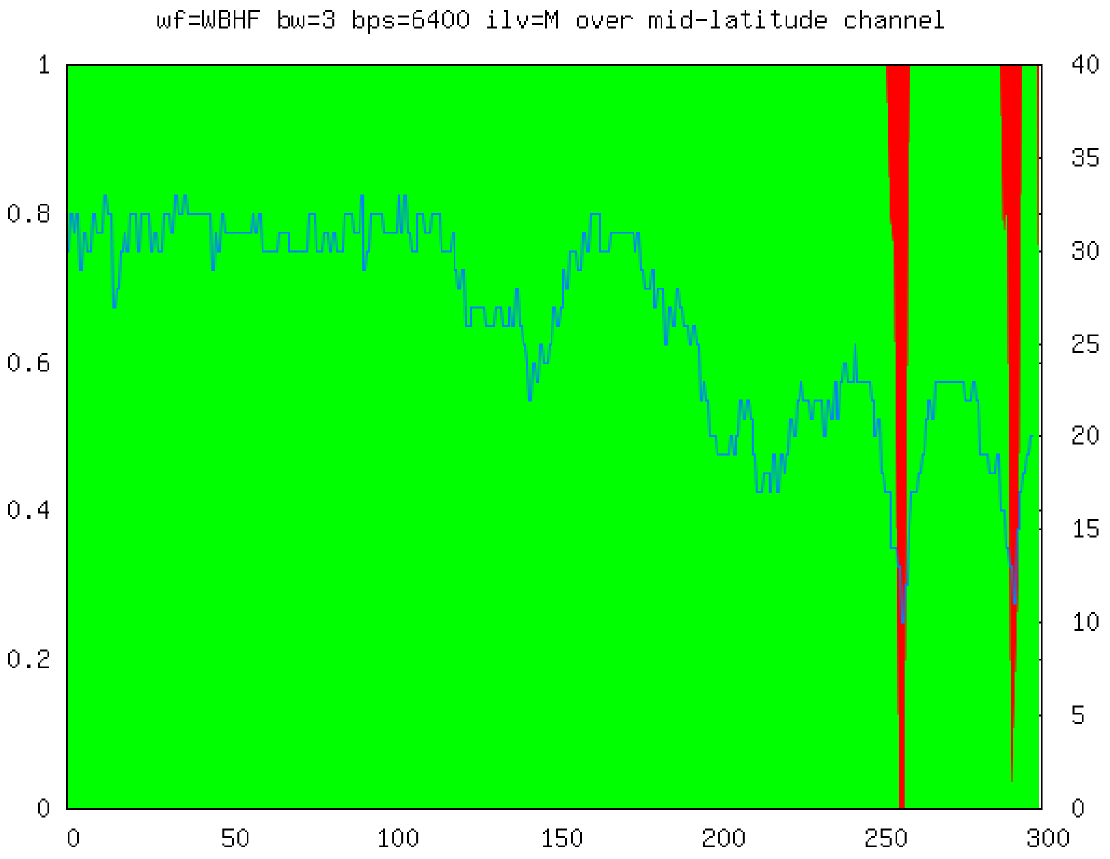
- This is the wideband waveform, bandwidth of 3 kHz, long interleaver
- The line show the measured SNR in dB, read along the right axis
- The colours show the proportion of data received correctly, read on the left axis, with green for success, and red for failure.
- When the SNR dips down, the waveform falls off the waterfall and proportion of valid data falls
- The interleaver length is visible in the evenness of size of the failing and successful regions



Isode

OTA example 2

We're quite interested in features that appear in real life that don't appear in simulation, such as these V-shaped drops in SNR, and swings of more than 20 dB.



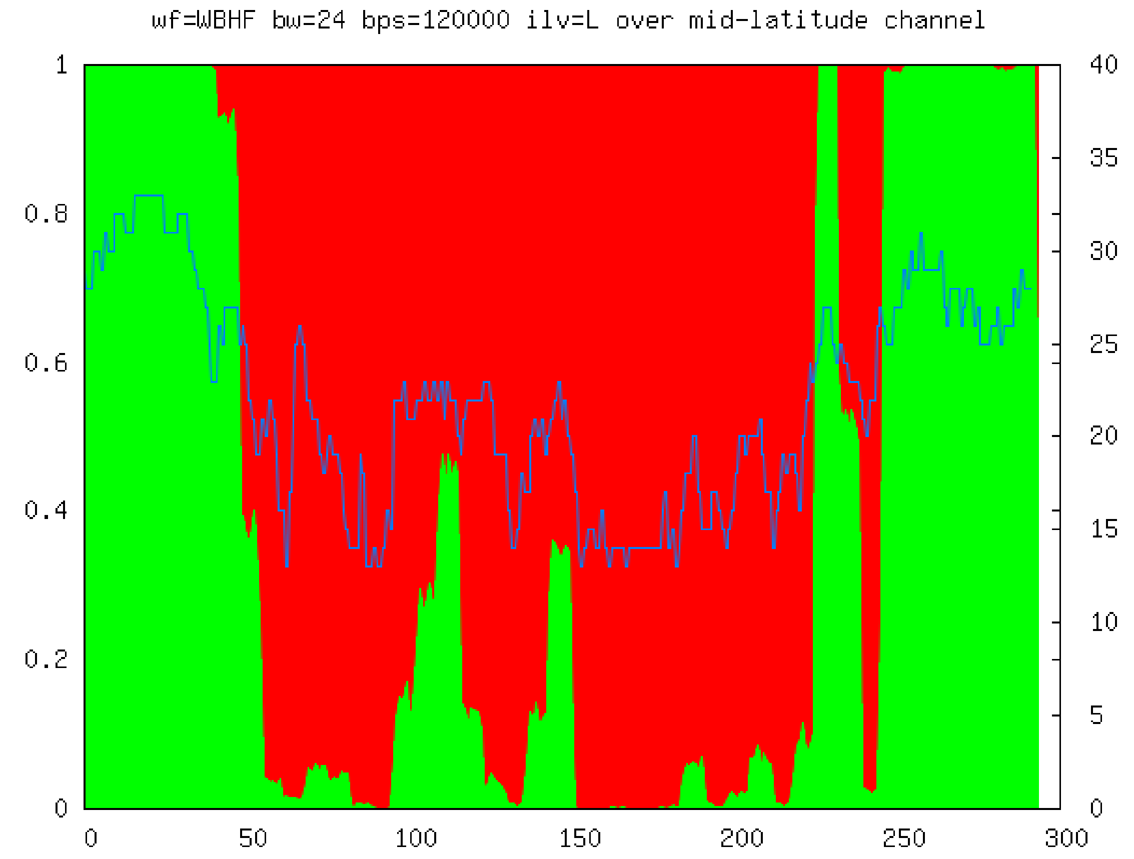
OTA example 3

This kind of pattern is going to give some errors in every transmission, so might benefit from duplicate retransmissions to bias towards a shorter window and shorter latency.

Isode

OTA example 4

This shows a 3-minute dip in SNR. This is an example of a change that would knock out a whole transmission, but if this was only occasional then there is no value in duplicating retransmissions or trying to adapt to it with data-rate-change.



Isode

Optimal DPDU Size Analysis

```
=== wf=WBHF bw=24 bps=76800 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *600*
  %Throughput:     50   62   68   70   74   75   76   77   77   77   77
=== wf=WBHF bw=24 bps=96000 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *400*
  %Throughput:     52   64   70   73   76   77   78   78   78   78   77
=== wf=WBHF bw=24 bps=38400 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     59   73   80   84   88   91   93   94   95   96   96
=== wf=WBHF bw=24 bps=51200 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     58   72   79   82   86   88   91   92   93   93   93
=== wf=WBHF bw=24 bps=51200 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     58   72   79   83   87   89   91   92   93   94   94
=== wf=WBHF bw=24 bps=64000 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     55   69   75   79   83   85   86   87   88   89   89
=== wf=WBHF bw=24 bps=51200 ilv=M
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     60   75   81   85   90   92   95   96   97   98   98
=== wf=WBHF bw=24 bps=64000 ilv=M
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     57   71   78   81   85   88   90   91   92   93   93
=== wf=WBHF bw=24 bps=76800 ilv=M
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     57   72   78   82   86   88   90   92   93   93   93
=== wf=WBHF bw=12 bps=25600 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     58   73   80   84   88   90   93   94   95   95   96
=== wf=WBHF bw=12 bps=32000 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     59   74   81   85   89   91   94   95   96   97   97
=== wf=WBHF bw=12 bps=38400 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     58   73   79   83   87   89   91   93   94   94   94
=== wf=WBHF bw=12 bps=25600 ilv=M
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     58   73   79   83   87   89   91   93   94   94   94
=== wf=WBHF bw=12 bps=32000 ilv=M
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     58   73   80   83   87   90   92   93   94   94   94
=== wf=WBHF bw=12 bps=38400 ilv=M
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     57   71   78   81   85   87   89   90   91   92   92
=== wf=WBHF bw=3 bps=6400 ilv=S
  CPDU seg size:   25   50   75  100  150  200  300  400  600  800 1000   *1000*
  %Throughput:     60   75   82   85   90   92   95   96   97   98   98
```

We ran some DPDU-length simulations against the recorded red/green patterns, optimising for throughput, to see what optimal DPDU lengths come out.

For the faster data rates available in WBHF, we saw no advantage in using anything less than the maximum. This is probably because the DPDU is so small compared to the data rate, perhaps only 70ms long in time.

For the faster waveforms of 4539, the maximum size also worked well. Nothing lower than 6400 bps was tested, though.

The only weird exception was that the optimal DPDU size for 8000 bps, 4539 waveform, with a 10-second interleaver turned out to be 150 bytes. Since the interleaver is around 10,000 bytes long in this case, the DPDU was optimising to be around 1.5% of the interleaver length in order to thread between scattered bit errors passing through the interleaver. I don't think it is practical to optimise to oddities of the interleavers like this in general, though!

Isode

Extrapolating DPDU Analysis to other rates

```
=== wf=WBHF bw=24 bps=76800 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    25    50    75   100   150   200   300   300   400   600
=== wf=WBHF bw=24 bps=96000 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    25    50    50    75   100   150   200   200   300   400
=== wf=WBHF bw=24 bps=38400 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:   100   100   200   300   300   600  1000  1000  1000  1000
=== wf=WBHF bw=24 bps=51200 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    75   100   150   200   400   400   800  1000  1000  1000
=== wf=WBHF bw=24 bps=51200 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    75   100   150   150   200   300   600   600  1000  1000
=== wf=WBHF bw=24 bps=64000 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    50   100   100   150   200   300   400   600   800  1000
=== wf=WBHF bw=24 bps=51200 ilv=M
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:   150   400   600   800   800  1000  1000  1000  1000  1000
=== wf=WBHF bw=24 bps=64000 ilv=M
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    50   100   150   200   400   400   600   800  1000  1000
=== wf=WBHF bw=24 bps=76800 ilv=M
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:   100   100   200   200   400   400   600   800  1000  1000
=== wf=WBHF bw=12 bps=25600 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:   100   150   300   300   600   600  1000  1000  1000  1000
=== wf=WBHF bw=12 bps=32000 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:   150   200   300   400   800   800  1000  1000  1000  1000
=== wf=WBHF bw=12 bps=38400 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    75   100   200   200   300   400   600   800  1000  1000
=== wf=WBHF bw=12 bps=25600 ilv=M
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:   100   150   200   300   400   800  1000  1000  1000  1000
=== wf=WBHF bw=12 bps=32000 ilv=M
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:   100   200   200   300   400   800   800  1000  1000  1000
=== wf=WBHF bw=12 bps=38400 ilv=M
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:    75   100   200   200   400   400   600   800  1000  1000
=== wf=WBHF bw=3 bps=6400 ilv=S
  For BPS rate:     75   150   300   600  1200  2400  4800  9600 19200 38400
  Best CPDU seg:  1000  1000  1000  1000  1000  1000  1000  1000  1000  1000
=== wf=WBHF bw=3 bps=8000 ilv=S
```

We very crudely extrapolated the error patterns from these tests to other data rates to see what this suggests about optimal DPDU sizes for those rates if the same pattern of errors occurred.

This is crude because it takes no account of interleaver lengths or how the waveforms react differently to the same interference.

Summary of extrapolated DPDU analysis

CPDU seg:	25	50	75	100	150	200	300	400	600	800	1000
75 bps	5	8	10	8	7	5		2			
150 bps	1	7	5	11	7	6	5	2	1		
300 bps	1	1	2	9	6	11	6	5	2	1	
600 bps		1	1	6	6	9	7	6	6	1	2
1200 bps		1		2	5	7	3	12	6	7	2
2400 bps			1	1	2	5	6	10	5	6	9
4800 bps				1	2	1	4	6	8	5	18
9600 bps					1	3	1	6	5	7	22
19200 bps					1	2	1	3	3	4	31
38400 bps					1	1	1	1	6		35

Window simulation based on OTA data

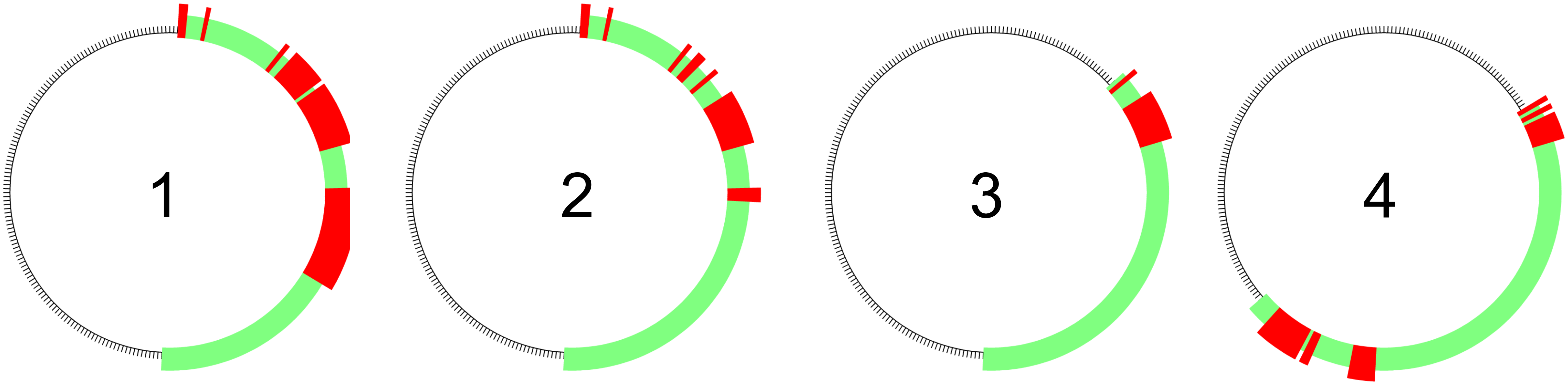
I'm now going to show the results of running a DPDU retransmission simulation against the data loss shown in this recording.

The simulation runs with the 4539 waveform at 8000 bps. The 5-minute error pattern is looped over and over to allow it to be applied to a longer test.

Isode

Window simulation, single retransmission

This diagram shows the window size (the red/green area) and within the window, which DPDUs need retransmitting.



You can see that after the first transmission, there are a number of DPDUs needing to be retransmitted, including one right at the start of the window which stops the window extending further.

After the second transmission, more of the failed DPDUs have been retransmitted and received, but still there are a number holding the window open.

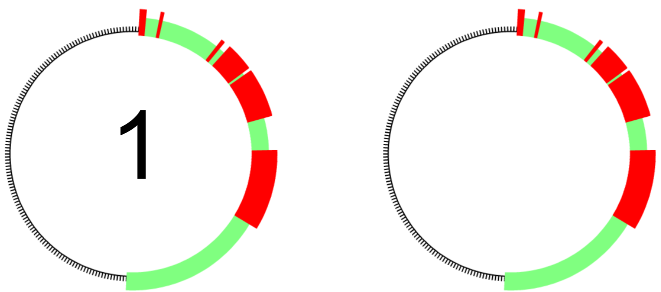
After the third transmission, the window has closed a bit allowing new DPDUs to be transmitted.

After the fourth transmission, we have advanced slightly further.

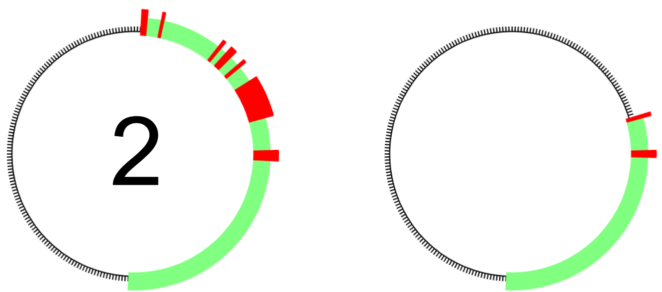
Isode

Window simulation single/double retransmission

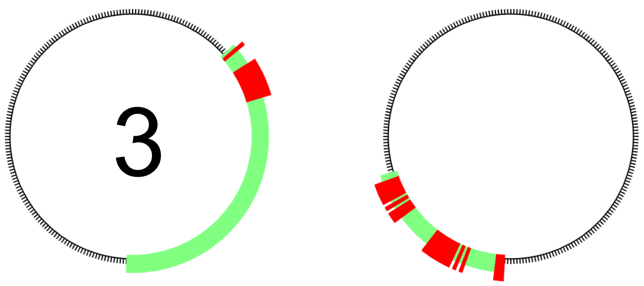
Now compare the situation if we retransmit each failed DPDU twice in the same transmission. On the left failed DPDUs are retransmitted only once, and on the right they are retransmitted twice.



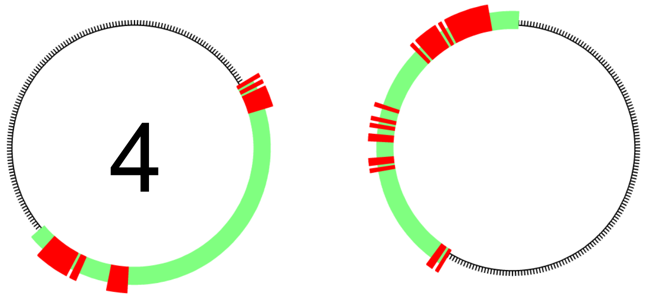
After the first transmission, they are in the same state.



But after the second transmission, the right side has already cleared some of the DPDUs holding the window open.



After the third, it has again cleared more failing DPDUs.



After the fourth, it is ahead by perhaps 80 DPDUs.

This is a small illustration of how duplicate retransmissions may help when the channel conditions create some errors in every transmission. The duplicate retransmissions reduce latency and help to keep the window smaller.

Isode

Using SNR recordings for simulation

Here is a half-hour recording of SNR taken from the recent tests.

We would like to add simulations to Morasky based on SNR recordings. Ideally we'd like SNR recordings that demonstrate odd things happening such as drop-outs or changes from one typical state of the ionosphere to another.

These odd happenings and changes are things that a data-rate-change algorithm needs to cope with. So we need to simulate them to test a rate-change implementation.

Isode

Simulating SNR effect through lookup tables

```
#Chan-Sim-                 -------- Measured -------- ---------------- Reported -------------------
#IF     SNR WForm Rate IL Drop   Pad    BER    CER Csiz BER     SNR DopOff DopSpr  MPSpr  MPCnt InpLev
AWGN     14 4539  9600  S    -     -   0.53   2.38 18.9 0.1    16.0    0.0    0.2    0.0    1.0  -10.7
AWGN     15 4539  9600  S    -     -   0.89   2.41  9.2 1.0    16.5    0.0    0.2    0.0    1.0  -10.7
AWGN     16 4539  9600  S    -     -   1.51   2.77  5.1 2.0    17.0    0.0    0.2    0.0    1.0  -10.7
AWGN     17 4539  9600  S    -     -   1.91   3.06  4.1 2.2    17.0    0.0    0.2    0.0    1.0  -10.6
AWGN     18 4539  9600  S    -     -   2.74   3.74  3.1 3.4    17.8    0.0    0.2    0.0    1.0  -10.6
AWGN     19 4539  9600  S    -     -   3.78   4.60  2.1 4.3    18.0    0.0    0.2    0.0    1.0  -10.7
AWGN     20 4539  9600  S    -     -   4.79   5.49  2.0 5.4    19.0    0.0    0.2    0.0    1.0  -10.7
AWGN     21 4539  9600  S    -     -      -      -    - 6.1    19.9    0.0    0.2    0.0    1.0  -10.8
AWGN     22 4539  9600  S    -     -      -      -    - 6.4    20.4    0.0    0.2    0.0    1.0  -10.7
AWGN     23 4539  9600  S    -     -      -      -    - 7.0    21.5    0.0    0.2    0.0    1.0  -10.6
AWGN     24 4539  9600  S    -     -      -      -    - ---    22.2    0.0    0.2    0.0    1.0  -10.8
AWGN     25 4539  9600  S    -     -      -      -    - ---    22.9    0.0    0.2    0.0    1.0  -10.8
AWGN    100 4539  9600  S    -     -      -      -    - ---    59.2    0.0    0.2    0.0    1.0  -10.8
#Chan-Sim-                 -------- Measured -------- ---------------- Reported -------------------
#IF     SNR WForm Rate IL Drop   Pad    BER    CER Csiz BER     SNR DopOff DopSpr  MPSpr  MPCnt InpLev
AWGN     14 4539  9600  M    -     -   0.49   2.40 21.7 0.1    16.0    0.0    0.2    0.0    1.0  -10.6
AWGN     15 4539  9600  M    -     -   0.77   2.35 10.3 1.0    16.1    0.0    0.2    0.0    1.0  -10.6
AWGN     16 4539  9600  M    -     -   1.26   2.60  6.3 1.7    17.0    0.0    0.2    0.0    1.0  -10.7
AWGN     17 4539  9600  M    -     -   1.80   2.99  4.5 2.1    17.0    0.0    0.2    0.0    1.0  -10.7
AWGN     18 4539  9600  M    -     -   2.98   3.98  3.0 3.5    17.9    0.0    0.2    0.0    1.0  -10.7
AWGN     19 4539  9600  M    -     -   3.69   4.58  2.6 4.4    18.1    0.0    0.2    0.0    1.0  -10.7
AWGN     20 4539  9600  M    -     -      -      -    - 5.4    19.0    0.0    0.2    0.0    1.0  -10.6
AWGN     21 4539  9600  M    -     -      -      -    - 6.1    19.8    0.0    0.2    0.0    1.0  -10.7
AWGN     22 4539  9600  M    -     -      -      -    - 6.7    20.6    0.0    0.2    0.0    1.0  -10.8
AWGN     23 4539  9600  M    -     -      -      -    - 6.9    21.5    0.0    0.2    0.0    1.0  -10.6
AWGN     24 4539  9600  M    -     -      -      -    - ---    22.3    0.0    0.2    0.0    1.0  -10.7
AWGN     25 4539  9600  M    -     -      -      -    - ---    23.3    0.0    0.2    0.0    1.0  -10.6
AWGN    100 4539  9600  M    -     -      -      -    - ---    58.4    0.0    0.2    0.0    1.0  -10.6
#Chan-Sim-                 -------- Measured -------- ---------------- Reported -------------------
#IF     SNR WForm Rate IL Drop   Pad    BER    CER Csiz BER     SNR DopOff DopSpr  MPSpr  MPCnt InpLev
AWGN     14 4539  9600  L    -     -   0.56   2.37 17.7 0.0    16.0    0.0    0.2    0.0    1.0  -10.7
AWGN     15 4539  9600  L    -     -   0.71   2.35 11.8 1.1    16.2    0.0    0.2    0.0    1.0  -10.6
AWGN     16 4539  9600  L    -     -   1.36   2.68  5.9 2.0    17.0    0.0    0.2    0.0    1.0  -10.8
AWGN     17 4539  9600  L    -     -   1.54   2.81  5.2 2.0    17.0    0.0    0.2    0.0    1.0  -10.8
AWGN     18 4539  9600  L    -     -   2.52   3.57  3.3 3.1    17.4    0.0    0.2    0.0    1.0  -10.6
AWGN     19 4539  9600  L    -     -   3.78   4.60  2.4 4.8    18.6    0.0    0.2    0.0    1.0  -10.7
AWGN     20 4539  9600  L    -     -   3.99   5.03  3.0 5.3    19.0    0.0    0.2    0.0    1.0  -10.9
AWGN     21 4539  9600  L    -     -      -      -    - 5.9    19.8    0.0    0.2    0.0    1.0  -10.7
AWGN     22 4539  9600  L    -     -      -      -    - 6.6    20.6    0.0    0.2    0.0    1.0  -10.6
AWGN     23 4539  9600  L    -     -      -      -    - ---    21.7    0.0    0.2    0.0    1.0  -10.6
AWGN     24 4539  9600  L    -     -      -      -    - ---    22.6    0.0    0.2    0.0    1.0  -10.8
```

For 4539, we already have tables of error rates and measured SNR for various channel simulations built into MoRaSky. Given a fixed SNR value, MoRaSky can simulate how the modem would react as the waveform is changed.

So maybe it is as simple as feeding changing SNR values into this code. However, we need to try this to see how realistic it looks compared to the live OTA measurements made in the recent tests.

Isode

Walnut Street

- Implemented in MoRaSky
- Doesn't simulate all the shifts and changes observed OTA
- DRC needs to ignore Walnut Street-like fluctuations!

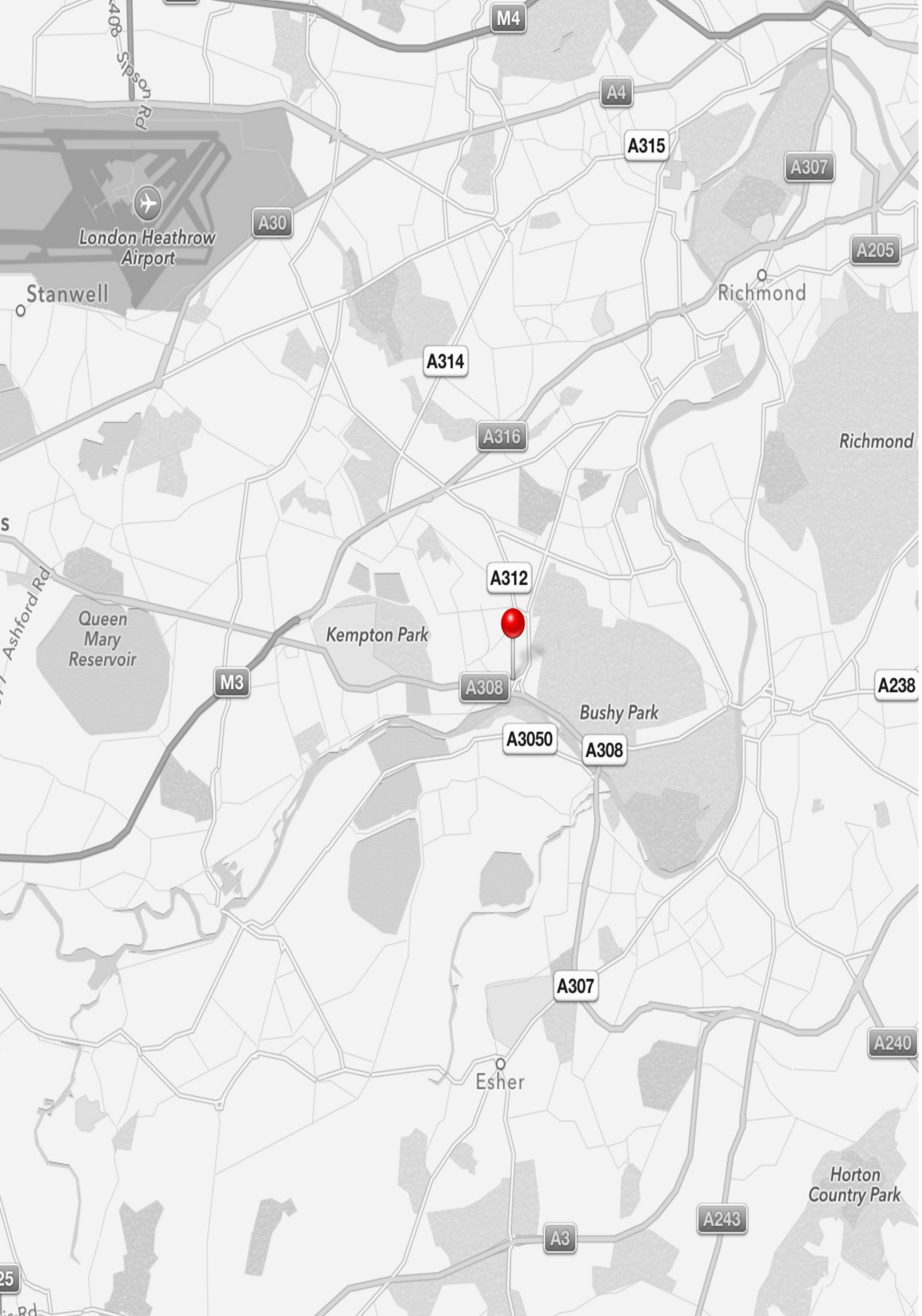
I already have an attempt at a Walnut Street simulation in Morasky (although I need to double-check my understanding of the maths). But that won't cover some of the shifts and changes observed in real life that a data-rate-change algorithm will nevertheless have to deal with. However it can serve as a test of what a data-rate-change algorithm needs to ignore.

For the Future

- Add better simulations to MoRaSky to more closely emulate real life
- Test established DRC algorithms against the simulation
- Try and develop new DRC algorithms

Both 'hftool' and MoRaSky are available to partners and integrators

Isode



Contact Information

Jim Peters
jim.peters@isode.com

Isode Ltd
14 Castle Mews
Hampton
TW12 2NR

www.isode.com

twitter.com/Isode_Ltd
linkedin.com/company/isode-ltd

Isode