Public service, APRS and the Internet of Things

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Abstract

In this paper we outline a prototype system assembled to improve situational awareness during a large public-safety event. This was done by integrating the use of SIGFOX^{TM}devices into a pre-existing Amateur Packet Reporting System (APRS^{TM}) systems and infrastructure. As the use of APRS mapping is well established at this event already, the most straightforward way to present the data was through existing systems. Lastly, we explain how ultra-low-power embedded systems based on SIGFOX devices were integrated and how they performed during a live trial.

Index Terms

Packet radio networks; APRS, Internet of Things, ultra-low-power communications;

I. Introduction

The Sean Kelly tour of Waterford (*The Sean Kelly or SKT* [1]) started in 2006 with approximately 900 participants. It has now developed into a two day festival with over 6500 participants and 500 volunteers. On the Sunday of the festival there are three cycling events with various levels of distance and difficulty: a 50k cycle event which is limited to 1500 participants, 100k event which is limited to 1900 participants, and 160k event which is limited to 1600 participants. The three events run over three different courses covering approximately, 200, 500 and 800 square km of land area respectively.

Civil Defence in Ireland [2] is a volunteer based organization made up of over 4500 members that support the front line emergency services with volunteers trained in: Casualty, Search and Rescue, Auxilary Fire Service, Radiation Monitoring, Welfare and Communications.

Civil Defence supports the frontline emergency services in dealing with severe weather, flooding, major accidents, fire fighting and searching for missing persons. Civil Defence supports hundreds of community events throughout the year. These include large events such as air shows, tall ships, concerts, festivals and sports events.

In this capacity, Civil Defence is the lead agency for medical support during the Sean Kelly tour. As the lead agency, Civil Defence avails of the medical volunteers of the Irish Red Cross (IRC) [3], Order of Malta Ambulance Core (OMAC) [4] and the communications expertise of the Amateur Radio Emergency Network (AREN) [5].

The IRC and OMAC between them provide 8-10 Ambulances and several fast response vehicles. Civil Defence runs the Emergency Operations Centre (EOC), provides another 2 ambulances along with 3 support 4x4 vehicles and a Doctor in the on-site medical center for the day. AREN assists with the setting up of the Emergency Operations Center, communications interoperability, filling in blackspots, and the use of APRS for tracking the broom wagon (last vehicle on the road) on each of the 50, 100, and 160k events as well as the Doctors vehicle. Several Civil Defence volunteers are also active in AREN.

On a normal Sunday, the National Ambulance service typically would have one Ambulance in the vicinity, with two more ambulances 40km away in Waterford City. No extra cover is provided by the National Ambulance service on the day.

Typically there are somewhere between 25 and 40 requests for medical assitance, with up to 10 transports to hospital during the day (heavily weather dependent).

II. Motivation

Due to the number of participants, the three alternate course routes and their geographic distribution, the SKT is resource intensive on all organizations. As there are known gaps in APRS coverage and due to lack of infrastructure and resources on the day, it has proven difficult to improve APRS coverage in any meaningful way. During the day, AREN members deploy 6 Byonics Micro-Trak AIO [6] units as well as several vehicles with various manufacturer's APRS capable radios. While appreciative of our efforts, the Civil Defence officer raised a question during a debrief after the 2015 *Sean Kelly* about whether it would be possible to increase tracking ability to include medical support vehicles. The ideal solution would be low cost, small footprint and quickly deployed, requiring no wiring to the vehicle. In looking for mechanisms to *fill-in-the-gaps*, one of the authors suggested looking towards the emerging *Internet of Things* for potential solutions on how to implement a pervasive, low power solution.

Our basic requirements were devices equipped with a GPS receiver capable of broadcasting their position to a distributed network in rural Ireland. The devices needed to be low power (battery if possible) and available for retail purchase. Not requiring an Amateur Licence would simplify device management. As APRS mapping is already in use through [7] and [8], being able to inject the data into the APRS Internet Service [17] would leverage existing infrastructure and applications.

The two suggested technologies to look at included LoRa [9] and SIGFOX [10]. It became obvious quite quickly that the deployment of SIGFOX in Ireland was far in advance of LoRa. In Waterford County, there is a planned deployment of some LoRa nodes by the Telecommunications Software & Systems Group [11] of Waterford Institute of Technology, but no solution or infrastructure was available to the authors when this paper was being written.

Consequently, at the commencement of this project, it seemed sensible to leverage VT Networks [12] SIGFOX network in Ireland (though, at the time of writing it still does not have 100 % coverage of the landmass of Ireland), so based on our proposed use, and constraints, the decision of which technology to use was relatively straighforward.

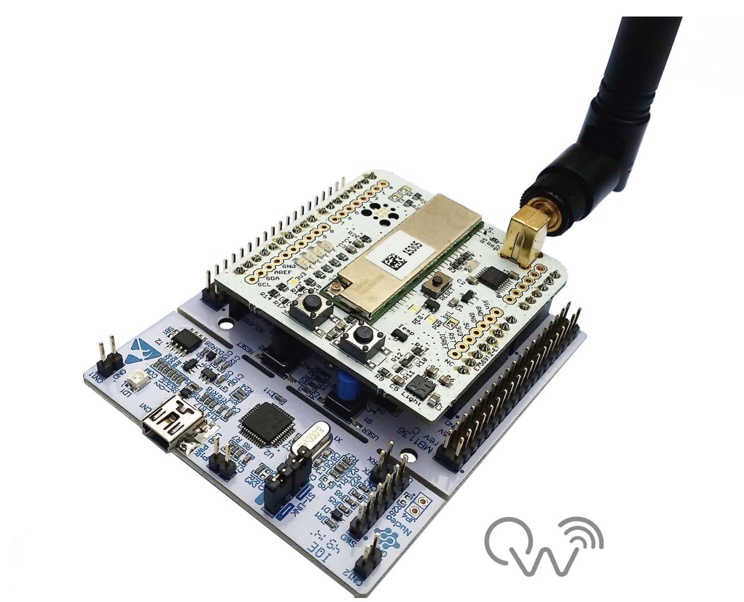

Fig. 1. Quicksand micro-electronics GPS Shield Development Kit

III. Implementation

After some research into off-the-shelf SIGFOX compatible devices, two Quicksand [13] micro-electronics development kits were purchased [14].

This development kit consists of an MBED Arduino compatible shield along with a SIGFOX TD1204 GPS Gateway and Transceiver device, access to code examples, and a years subscription to the SIGFOX network. As well as the onboard multi

GNSS support (GPS/GLONASS), there are various other sensors including temperature, accelerometer, proximity, ambient light, programmable LEDs and user buttons.

The functionality of SIGFOX devices satisfied our technical requirements but there were two further considerations. First the cost. There is an annual cost for SIGFOX devices to be given access to the network. Based on figures supplied by VT Networks (for less than 1000 devices) that comes to €10.50 ($12 approx.) per device per annum. Secondly, each device is restricted to 140 messages per day or less than 1% duty cycle on the network. This equates to a maximum of 36 seconds per hour of transmission time. As each 12 byte transmission takes up to 6 seconds, this equates to 6 transmissions per hour approximately.

SIGFOX devices operate in the ISM bands between 868.1 and 868.3MHz, with a maximum radiated power of 25mW using 100bps DBPSK modulation. For tracking medical support vehicles, 140 messages per day or 6 transmissions per hour, should adequately address our required resolution of positional information as the vehicles spend most of their time strategically parked, awaiting deployment instructions from the EOC.

The TD1204 device chosen has the following characteristics [15]:

- Frequency range = ISM 868 MHz
- Recieve sensitivity = -126dBm
- Modulation = (G)FSK, 4(G)FSK, GMSK, OOK
- Max output power = +14dBm
- Low active radio power consumption
  - 22μA RX (windowed mode)[1]
  - 37mA TX @ +10dBm

A. The Quicksand TD1204 Development kit

Getting the development kits operational was easier than expected. There is an online compiler available at http://developer.mbed.org. Some minor modifications[2] were made to one of the code examples, and messages started to emanate from the development kit.

Using the development kit as it stands, with no attempt at optimization, a power consumption figure of approximately 31mAh at 5 Volts was measured over a 36 hour period.

B. Decoding the SIGFOX data packet

As mentioned above each data transmission from the development kit consists of 12 bytes of data. As an example, take this frame **5d01010067442b6337a03c99**, which was received from one of the development kits. This frame can be divided into sections as per Figure 2, and is examined in more detail in Figure 3.

C. SIGFOX servers and callbacks

The SIGFOX server infrastructure allows the use of callbacks. These can be used to transfer data received from a SIGFOX device out of the SIGFOX network for further processing (see full overview in Figure 4). In this case, a simple *HTTP GET* Method was used to call a PHP CGI script (see Figure 5 for sample callback). For debugging purposes the PHP script (webhook), saves the the full URL to a text file (see Figure 6 for actual data).

This PHP script also decodes the GPS location and saves it in APRS format along with the number of visible satellites and a measure of the Horizontal Dilution of Precision (HDOP).

Finally the PHP script publishes all the available fields from the SIGFOX infrastructure as MQTT [16] messages to an MQTT message broker. See Figure 7 showing typical output from an MQTT subscriber.

[1] Listen for one frame, then switch off receiver for one second

[2] Code available at https://github.com/jpronans/sigfox2aprs

-	Frame Type	GPS Position	Signs/Altitude	No of Satellites and HDOP
0x5d0	0x1010	0x067442b6337a	0x03c	0x99

Fig. 2. Field Breakdown

Bits	Hexadecimal	Decimal	Description/Meaning
0 - 8	0x5d	93	Unknown
9 - 12	0x0	0	Reserved
13 - 28	0x1010	-	GPS Frame
29 - 48	0x067442b6337a	7096405209978	7° 09.640' 52° 09.978'
49 - 60	0x03c	60	* 2 => 120m Altitude
61	1	1	long. sign { 0 = pos., 1 = neg.} => 1 => -7° 09.640'
62	0	0	lat. sign { 0 = pos., 1 = neg.} => 0 => 52° 09.978'
63	0	0	alt. sign { 0 = pos., 1 = neg.} => 0 => +120m
64 - 66	-	6	satellites in view => 6
67 - 68	-	1	horizontal dilution of precision => 0 (good) to 3 (bad)

Fig. 3. Known fields in a SIGFOX frame

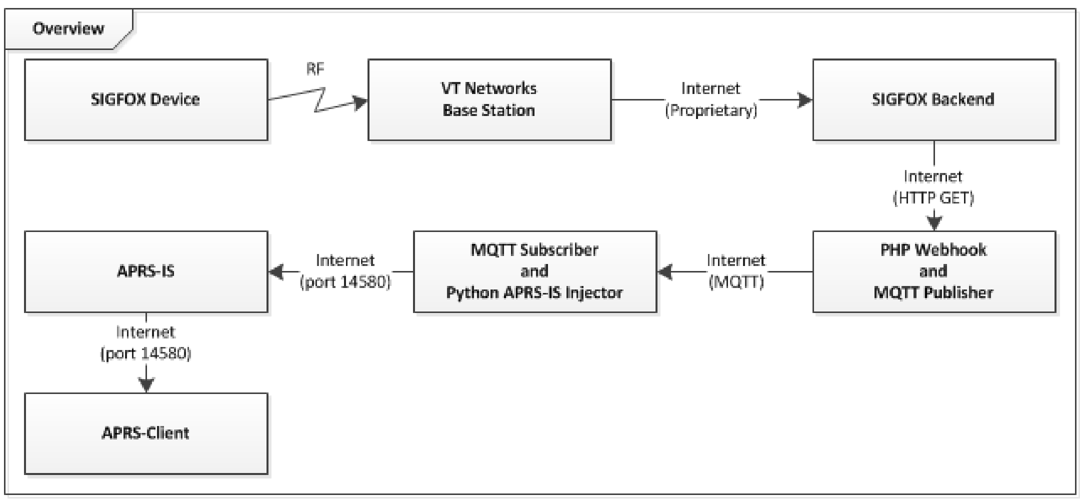

Fig. 4. System overview

D. Message Queue Telemetry Transport (MQTT)

MQTT is a publish/subscribe lightweight messaging protocol, designed for constrained devices and low-bandwidth, high-latency or unreliable networks. The design principles are to minimise network bandwidth and device resource requirements while also attempting to ensure reliability and some degree of assurance of delivery. These principles also turn out to make the protocol ideal for the emerging machine-to-machine (M2M) or Internet of Things world of connected devices, and for mobile applications where bandwidth and battery power are at a premium. There are implementation libraries for the MQTT broker and subscriber components available for most programming languages. The use of MQTT was mostly based on prior experience with the protocol. In this project, it meant that the (PHP) script generating the MQTT data, is completely decoupled from the script consuming the data (A python based MQTT subscriber that injects packets into the APRS Internet Service). It also allows the flexibility for other decoupled applications to subscribe to the data feed.

E. MQTT to APRS

A Python script (MQTT subscriber) consumes these messages and uses them to create APRS Position and Telemetry packets. In fact it produces two packets. A position and a telemetry packet. This whole

```
http://myhost/callback.php?id={device}&time={time}&duplicate={duplicate}&snr={snr} \
&station={station}&lat={lat}&lng={lng}&rssi={rssi}&data={data}&avgSnr={avgSnr}&seqNumber={seqNumber}
```

Fig. 5. Example SIGFOX HTTP GET callback

```
http://myhost/callback.php?id=1511B&time=1469389143&duplicate=false&snr=12.59 \
&station=2252&lat=53&lng=-7&rssi=-139.00&data=5501010067442b6337b03e9c&avgSnr=24.87&seqNumber=929
```

Fig. 6. Received URL from HTTP callback

```
sigfox/1511B/lat 5209.97N
sigfox/1511B/lng 00709.64W
sigfox/1511B/sats 6
sigfox/1511B/hdop 0
sigfox/aprs 1511B:5209.97N:00709.64W:6:0
sigfox/1511B/time 1469389143
sigfox/1511B/duplicate false
sigfox/1511B/snr 12.59
sigfox/1511B/station 2252
sigfox/1511B/rssi -139.00
sigfox/1511B/avgSnr 24.87
sigfox/1511B/seqNumber 929
sigfox/telem 1511B:929:12.59:24.87:-139.00:6:0
```

Fig. 7. MQTT messages as seen from output from mosquitto_sub tool

process, from the information arriving into the SIGFOX infrastructure, to the packet appearing on the APRS-IS, appears to take approximatly 2 seconds.

```
EI0AC-9>APZWIT:!5209.98N/00709.63Wa Sats:6 HDOP:1 Unit:1511B
EI0AC-9>APZWIT:T#168,011,024,139,006,001,00000000
```

Fig. 8. APRS Position and Telemetry packets as inserted into APRS-IS

F. Initial Tests

Initial tests of the unit were done with the unit static on the workbench just to make sure everything was working as expected and the code was reasonably robust.

The next stage involved it being placed into the vehicle of one of the authors and accompanying him on his daily commute.

The screenshot in Figure 10 shows the track from one of these test runs. The recorded positions are approximately 10 minutes apart as expected. The test unit was left running for several weeks in order to see how well it performed in this non-ideal location. Given the rather poor mounting location in the vehicle (see Figure 9), it was a pleasant surprise to see the coverage afforded by VT Network's base stations.

IV. Trial Results

It was decided as part of the trial to put the available units into two Civil Defence ambulances. These vehicles are identical to that in Figure 11. The SIGFOX units were mounted in the area above the drivers head (behind the "Ambulance" lettering). The entire rear of the body of this type of ambulance is fibre-glass. So positioning the unit here keeps it out of the way of any personnel.

These vehicles act as moving first-aid posts during the event. Essentially leapfrogging between rest stops, when all the cyclists leave one location, the ambulance will move to the next rest stop. After

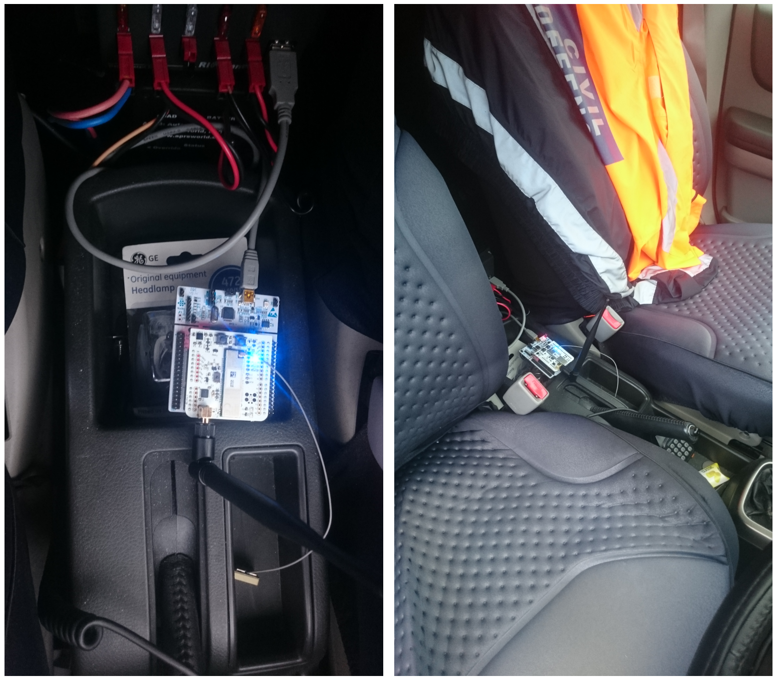

Fig. 9. Mounting location of the development board for initial tests.

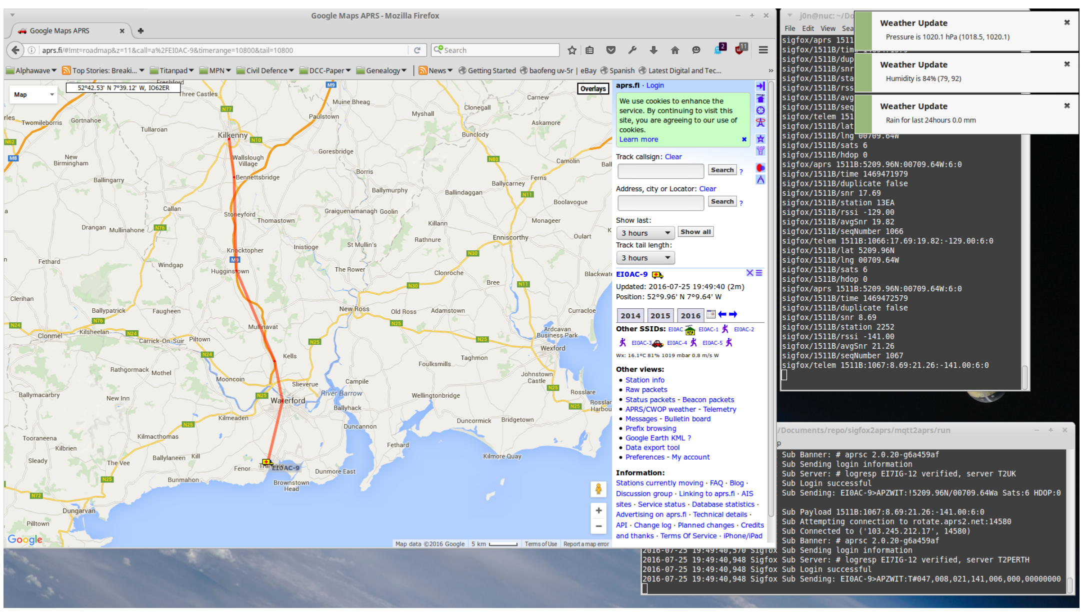

Fig. 10. Screenshot showing station track visible on http://aprs.fi

the last rest stop, the vehicles are generally tasked to follow the course stopping at various strategic locations where it is safe to do so. Sometimes, however, an ambulance may be redeployed to another route entirely.

The first issue that occured on the day was difficulty with maintaining Internet connctivity with a portable hotspot. Once it was ascertained that it was not the laptop had the problem, we proceeded to tether with a mobile phone. This worked fine for the rest of the day.

Second lesson learned on the day was that the some portable USB ‘charging’ packs for mobile phones, even when manually switched on, will turn themselves off after a period of time. One such unit that

Fig. 11. Civil Defence Ambulance

was deployed on the day switched off after approximately one hour, consequently switching off one of our test devices. Several units were tested in advance, and we can only assume that one ‘unsuitable’ unit slipped through our testing.

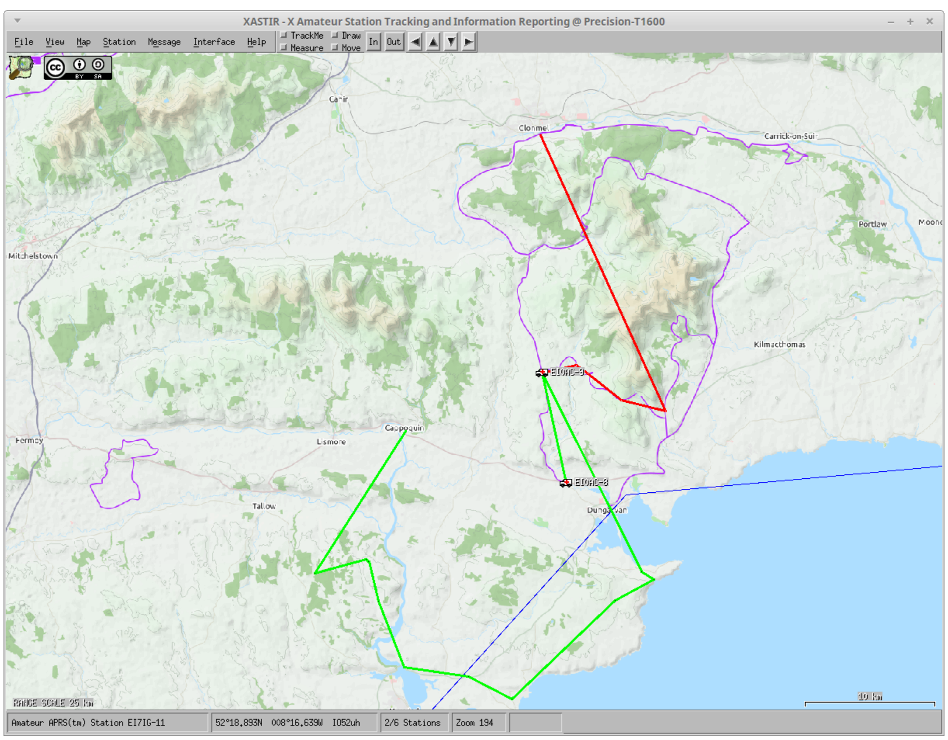

Fig. 12. Screenshot showing recorded positions of Ambulances.

Figure 12 shows the result. It seems that EI0AC-8 (Southern track), had some issues early on on the day, which we believe to be the USB lead getting accidentally pulled out of the battery. Once it was checked and powered back up, it gave a useful number of beacons. Also, it gave beacons where we had no radio communications with the ambulance, this was a surprise. Analysing the data, there were a further 15 position beacons that never made it to the SIGFOX network and hence were missed.

EI0AC-9 (Nothern Track), really didn't work very well initially. However it did start working towards the end of the day. This unit had the battery back that switched itself off.

As all EOC personnel were informed that the units were programmed to send their position every ten minutes. All personnel checked the age of the position on the Xastir display before calling the ambulances for a position report. This worked well and reduced the volume of radio traffic.

V. Conclusion & Further work

Figure 13 shows the overall map towards the end of the day. The screenshot does not do it justice, but at this point both ambulances were being tracked and the map was being constantly referred to while decisions were being made how to allocate medical resources.

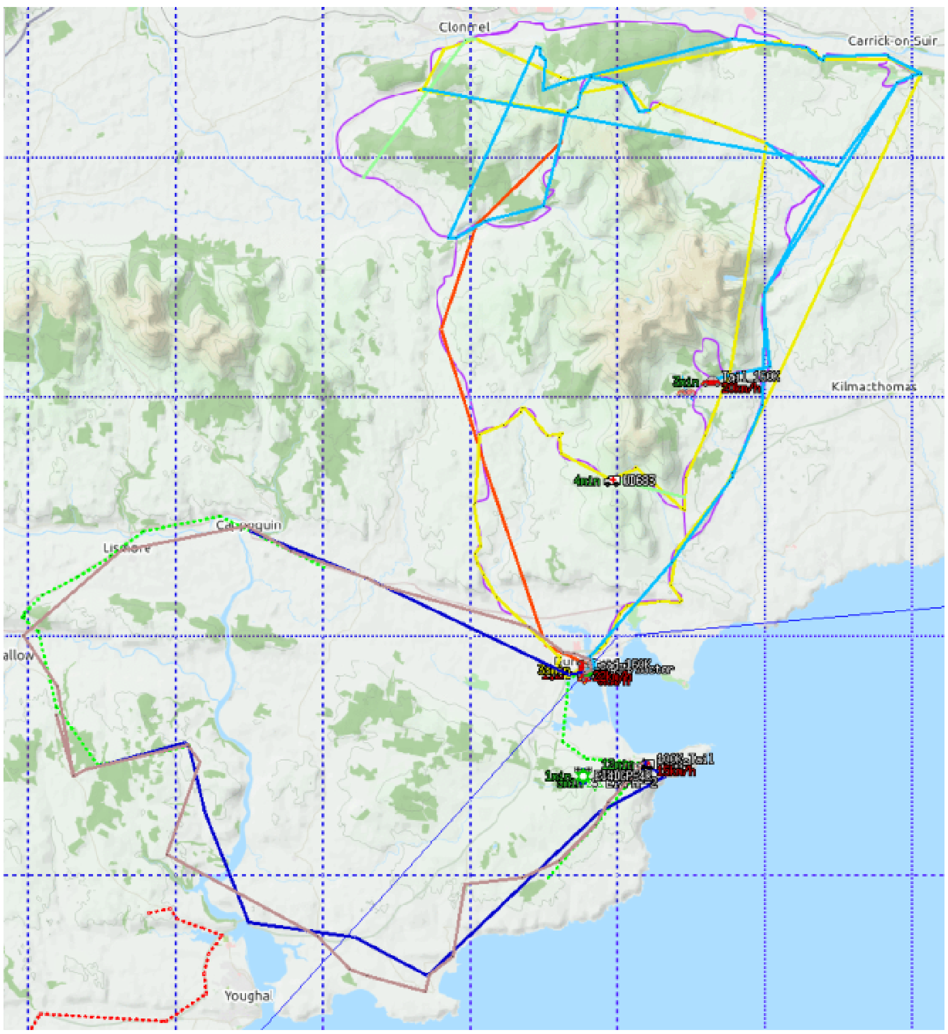

Fig. 13. Screenshot showing map towards the end of the day.

There are several improvements that we could make to this prototype. Firstly a more reliable power source is needed. The issues seen were primary due to lack of testing our our behalf beforehand and should have been avoided. An other obvious improvement would be to use either a GPS geofence or the accelerometer to detect movement, and only generate a beacon on these events. Also, the GPS could be shutdown between beacons. No doubt, these changes would increase battery life, though as the units are designed for low power consumption, it remains to be what the impact power savings would have, given this scenario.

Our software performed flawlessly on the day, but, there are still improvements that could be made. Principally, the improvements would be in the form of improved diagnostic and debugging information for reviewing what happened after the fact. Also, we could increase the reliability of the APRS-IS injection by running a second instance of the python script. Should the first instance fail, then this would ensure our packets make it into the APRS-IS.

Another area to be considered is the possibility of generating a SIGFOX network coverage map using the data received from a unit installed in a vehicle travelling around the Irish countryside. Our data indicates that the Irish SIGFOX network coverage is not as extensive as indicated to a device in-the-field. Possiblities for such a study are being actively investigated at present.

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