



EVERYTHING THAT MOVES, ON THE MAP

AN APRS-STYLE GPS POSITION NETWORK, RELAYED BY THE SURVEYOR, PUBLISHED AS MQTT

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How every aircraft, crew, vehicle, landing site, dip tank and marker on an incident carries a small GPS beacon of our own design, how the surveyor relays those beacons over terrain, how the command node turns them into MQTT messages that the CCR decision core and every other subscriber can use, what protocol and radio band to use so the system is legal for a commercial operation in the United States, and how to build the first version from the LoRa hardware already on hand.

01

What the position network is for

The fire state model and the CCR planners are only as good as their knowledge of where things are. Aircraft positions come from the telemetry link while it is up; everything else — a crew walking a handline, a water tender on a forest road, a new helispot cleared an hour ago, a dip tank dropped by a tender, the fuel truck, a hand-carried designator, a marker set — has no telemetry link at all. The position network gives all of them one cheap, low-power, long-range way to say “I am here, I am this, and here is one line of status” every few seconds, and gives the aircraft a second, independent position channel for when the main telemetry link drops.

The model it follows is APRS, the amateur-radio Automatic Packet Reporting System: short unconnected position packets, digipeated by whichever station hears them, gated into an internet backbone and consumed by anyone who subscribes. The surveyor is the digipeater; the command node is the gateway; MQTT is the backbone.

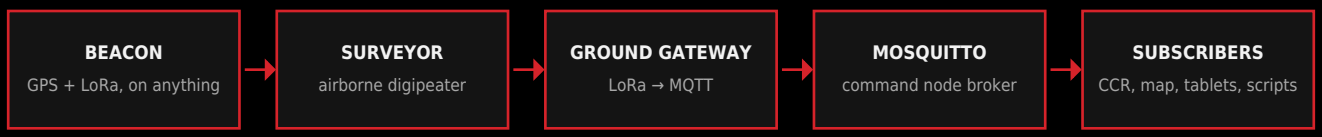


Figure 1 — the path of one beacon. Beacons the gateway can hear directly need no relay; the surveyor fills in the terrain shadows.

02

Why it cannot be real APRS, and what to use instead

Classic APRS runs on amateur-radio frequencies (144.390 MHz in North America, AX.25 at 1200 baud; LoRa-APRS at 433.775 MHz in Europe and in the 902–928 MHz band in the U.S.). A commercial firefighting contractor cannot use it. 47 CFR § 97.113 prohibits an amateur station from transmitting communications for hire or compensation, or in which the licensee has a pecuniary interest, including on behalf of an employer; the only exception is a limited emergency-preparedness drill. The Part 97 bandwidth limit on 70 cm also makes the standard 125 kHz LoRa-APRS channel illegal there. So the APRS idea is kept and the amateur band and licence are not.

Option	Band / rule	Legal for a commercial operation?	Assessment
Classic APRS, 144.39 MHz AX.25	Amateur, Part 97	No (§ 97.113)	Rejected; also 1200 baud and crowded
LoRa-APRS on 433 MHz	Amateur 70 cm, Part 97	No; 125 kHz LoRa also exceeds Part 97 bandwidth on 70 cm in the U.S.	Rejected in the U.S.; fine for a European demo
Own LoRa beacon protocol, 902–928 MHz	ISM, Part 15.247 (digital modulation, up to 1 W conducted; antenna-gain rules apply)	Yes, unlicensed, with certified modules	Selected. Same hardware as LoRa-APRS, our own packet format
Meshtastic (LoRa mesh, 915 MHz)	ISM, Part 15	Yes	Useful reference; NASA's 2025 STORMBHRD test found its channel-utilisation throttling struggles with high-rate UAS telemetry — keep the mesh idea, drop the firmware
Licensed Part 90 data channel (450 / 900 MHz)	Licensed, coordinated	Yes, with a licence	Option for the operational fleet when more power or a protected channel is needed
Cellular / satellite trackers	Carrier	Yes	No coverage on most fires; backup for ferry flights only

The selected option keeps everything that makes APRS good — tiny packets, store-and-forward digipeating, one shared channel, trivially cheap hardware — on a band where a company may operate without an amateur licence, using FCC-certified LoRa modules so that no new equipment authorisation is needed. If the fleet later needs a protected channel, the same packet format moves to a licensed Part 90 radio without changing anything upstream.

03

Radio layer

Parameter	Choice	Why
Band	915 MHz ISM (902–928), FCC-certified SX1262-class modules	Unlicensed commercial use; penetrates vegetation better than 2.4 / 5.8 GHz; antennas are small
Modulation	LoRa, BW 125 kHz, SF 9 for beacons (SF 7 on the air-to-ground leg), CR 4/5	SF 9 gives roughly 15–20 dB of link margin over SF 7 at about 1.8 kbit/s; the surveyor leg has line of sight and can use a faster setting
Power	+20 to +22 dBm on beacons, +27 dBm on the surveyor relay, within Part 15.247	100–150 mW is enough for several km on the ground and tens of km to an aircraft in sight
Range	Ground-to-ground 2–8 km in terrain; ground-to-surveyor 20–40 km line of sight; mLRS-class LoRa links report 7–87 km	A surveyor at 2,500 ft AGL sees a 100 km radius; terrain, not power, sets the ground range
Channel plan	One shared beacon channel + one relay channel; frequency hopping across a few channels if the band is noisy	Keeps beacons off the main telemetry and video links entirely
Hardware	Beacon: ESP32-S3 + SX1262 + u-blox M10 GNSS + 18650 cell, in a weatherproof box (Heltec V4 / TTGO class). Relay: same radio on the surveyor's companion computer. Gateway: SX1262 on the command node	US$ 25–60 per beacon; the four TTGO H251 915 MHz boards and the Heltec V4 on hand are exactly this class

04

Packet format: APRS, simplified and typed

Each beacon transmits a fixed-layout binary packet of about 30 bytes, which fits in one LoRa frame with room for a payload. Fields are typed so the gateway can convert them to MQTT without parsing free text, and every packet carries a type code so subscribers can filter.

```
byte 0 protocol version
byte 1 station type: 1 surveyor, 2 suppressor drone, 3 helicopter, 4 crew, 5 vehicle, 6 helispot,
7 dip site, 8 fuel point, 9 marker set, 10 designator, 11 weather node
bytes 2-5 station id (32-bit; printed on the box, bound to a name in the command node)
bytes 6-9 latitude (int32, 1e-7 deg) bytes 10-13 longitude (int32, 1e-7 deg)
bytes 14-15 altitude (int16, m, ellipsoidal) bytes 16-17 course/speed packed
bytes 18-21 GPS time (uint32, s) byte 22 fix quality + satellites
byte 23 battery % byte 24 status code (see table)
bytes 25-28 status value (uint32; litres, kg, count, or packed text)
byte 29 hop count (0 origin, 1 relayed once) bytes 30-31 CRC-16
```

Station type	Beacon interval	Status value carries
Aircraft (surveyor, drone, helicopter)	2 s moving, 10 s hovering; also the fallback position source if the telemetry link drops	Battery % or fuel kg; mission state code
Crew leader / designator	15 s moving, 60 s static; immediate on trigger press	Crew size; designator request code and bearing
Vehicle (tender, fuel truck)	10 s moving, 120 s static	Water or fuel on board, litres
Helispot, dip site, fuel point	120 s static (fixed asset, rarely changes)	Status: open / closed; litres available; approach heading
Marker set	300 s	Set id and which markers are powered
Weather node	60 s	Wind, temperature, humidity packed

Collision handling is APRS-style: random jitter on every interval, listen-before-talk, and smart beaconing on moving stations (transmit sooner on a heading change, slower when straight and steady). With forty stations at these rates the shared channel runs at well under 10 % utilisation.

05

The surveyor as digipeater

The surveyor's radio listens on the beacon channel, stores every packet it hears, de-duplicates by station id and time, and re-transmits the batch on the relay channel toward the gateway once a second. It is a one-hop digipeater by rule: it relays only packets with hop count 0, so nothing loops and the air-to-ground leg carries each position exactly once. If the gateway is also within direct range of a beacon it sees the packet twice and keeps the earlier copy.

- Why one hop is enough. From 2,500 ft AGL the surveyor sees every beacon within tens of kilometres; there is no terrain between it and the valley floor that a second hop would fix.
- Two surveyors. When a second surveyor is on station both relay; the gateway de-duplicates. A relay packet carries the relaying surveyor's id, so the model also knows which surveyor can hear which station — a free coverage map.
- Store-and-forward. If the gateway link is down the surveyor keeps the last position of every station for 10 minutes and dumps them when the link returns, so a track is never lost, only delayed.
- Reverse direction. The relay channel is bidirectional at low rate: the command node can send a short acknowledgement or a text to a beacon (“drop approved”, “move to helispot 3”) through the surveyor. Beacons with a display show it; beacons without one blink an LED pattern.
- Independence from the telemetry link. The relay runs on the surveyor's companion computer with its own radio and antenna, and nothing in it depends on the main telemetry or video links. When those fail, this is the channel that still tells the Commander where everyone is.

06

Gateway and MQTT

The gateway is a small service on the command node (the same Mosquitto broker the rest of the system uses) that decodes each packet, looks up the station id, and publishes it. Topics are designed so that a subscriber can take exactly the slice it needs with one wildcard.

```
pos/<type>/<station> retained; last position JSON
pos/<type>/<station>/track not retained; every fix, for history
status/<type>/<station> retained; battery, fuel, litres, state code
asset/helispot/<id> asset/dip/<id> asset/fuel/<id> retained; fixed assets with capacity and
open/closed
request/designator/<station> not retained; a drop request with bearing and crew id
relay/<surveyor>/heard retained; list of station ids heard in the last minute (coverage)
cmd/<station> downlink text or ack, routed back through the surveyor
```

Payload example for `pos/crew/0x1A2B`:

```
{"t":"2027-03-14T15:42:07Z","lat":37.284311,"lon":-107.019642,"alt":2378,"crs":215,"spd":1.1,"fix":3,
"sats":11,"bat":84,"status":"moving","val":6,"name":"Crew 3 leader","via":"SURV-1","age_s":1.4}
```

Who subscribes

Subscriber	Subscribes to	Uses it for
Fire state model / CCR	pos/#, status/#, asset/#, request/#	Aircraft fallback positions, crew separation rule, water and fuel availability, designator requests as tactical options
Commander's map	pos/#, asset/#	Every station on the map with age and status; grey when stale
Separation monitor	pos/crew/#, pos/+/+	Alarm if any planned drop line comes within the published distance of a crew beacon
Logistics script	status/vehicle/#, asset/fuel/#, asset/dip/#	Fuel and water stock per site; tells CCR when a dip site is empty or a fuel point is dry
Recorder	#	Full incident replay for after-action review
Property automation (home use)	pos/vehicle/#	The same beacon in a car triggers the gate lights on approach — the gate-light project runs on this network unchanged

07

First build with the hardware on hand

1. Beacons: the four TTGO H251 915 MHz boards and the Heltec WiFi LoRa 32 V4, each with a u-blox M10 GNSS module and an 18650 cell, in a weatherproof box with a short 915 MHz whip. Firmware: ESP32 Arduino or ESP-IDF, the packet format above, smart beaconing, listen-before-talk.

2. Gateway: one more board on a USB serial link to the command node, or the SenseCAP M2 / Dragino gateway reflashed to raw LoRa (not LoRaWAN — LoRaWAN's join and duty-cycle machinery adds nothing here and gets in the way of a shared beacon channel). A Python service decodes and publishes to Mosquitto.
3. Surveyor relay: a board on the surveyor's companion computer with a vertical antenna, running the one-hop digipeater firmware. For the demonstration the surveyor drone carries it; for a fixed-wing surveyor the same box goes in the fuselage.
4. Test on the property first. Beacons on two vehicles, a crew beacon on a person walking the 120 acres, the relay on a pole on the ridge standing in for the surveyor, the gateway on the existing Mosquitto broker. Measure packet success rate by distance with and without the relay, then move to the drone.
5. Demo day: beacons on the three drones (as the fallback position source), one per crew member, one on the dip tank, one on the landing mat, one in the hand-held designator. The Commander's tablet shows all of them from the first minute, before the video or telemetry links are even up.

Sources: 47 CFR § 97.113 and § 15.247 (eCFR, current); APRS Foundation, “LoRa APRS: Bringing APRS into the 21st Century” (2024, updated 2026); NASA TM-20250008167, STORMBHRD Meshtastic UAS telemetry test (2025); ArduPilot mLRS documentation (range figures); Semtech LoRa drone communications note. Range and cost figures are engineering estimates for the stated hardware.