



WHAT GOES WHERE

TELEMETRY ROUTING FROM SECTOR ASSIGNMENT TO DROP, AND MULTI-CHANNEL VIDEO FOR HUMANS AND FOR CCR

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The complete data plan of an incident: which messages exist, who publishes them, who subscribes, and over which link they travel — from the first sector handed to the surveyor, through detection of fires or hot spots, to the CCR planners' allocation and the aircraft's drop cards; the vital and mechanical telemetry that lets CCR recall a drone at bingo or route a helicopter to a fuel point that still has fuel; and the video architecture that delivers every camera raw to the Commander and, in parallel, to the analytics that feed the fire state model.

01

Three links, one broker, one rule

Every aircraft and every ground element has up to three radio paths, and the design rule is that each message is published once to one MQTT topic and routed over whichever link is up, so that no subscriber needs to know where a message came from.

Link	Carries	Technology	When it is the path
Position network (915 MHz LoRa)	Positions, one line of status, designator requests, short commands	Own APRS-style beacons, surveyor digipeater (see the position-network paper)	Always on; sole path for crews, vehicles and fixed assets; fallback for aircraft
Telemetry / C2 (IP data link)	Full MAVLink telemetry, mission upload, drop cards, MQTT itself	Demo: mLRS or WFB-ng bidirectional MAVLink; operational: Microhard / Doodle Labs / Silvus-class IP radio	Primary for every aircraft while in link; relayed by the surveyor for aircraft behind terrain
Video (IP, wide band)	Thermal and EO streams, one or more per aircraft	Demo: WFB-ng 5.8 GHz; operational: COFDM / MANET radios, licensed where needed	Continuous from the surveyor; on demand or continuous from assistants by priority

The broker is Mosquitto on the command node, with a bridged replica on the surveyor's companion computer so that an aircraft which can only reach the surveyor still reaches the broker. Aircraft publish over the IP link with MQTT; where only the LoRa beacon channel is left, the gateway publishes the beacon fields to the same topics with a lower `quality` flag. Retained topics hold last-known state; non-retained topics carry streams and events.

02

The topic tree

```
incident/<id>/sector/<n> retained polygon, priority, assigned surveyor, status (Commander → surveyor)
incident/<id>/model/fire/<fid> retained polygon(t), ROS, flame length, projection, confidence
(processing → all)
incident/<id>/model/hotspot/<hid> retained point, temp, first seen, growing?, verified? (processing →
CCR, map)
incident/<id>/model/asset/<aid> retained structure/road/crew/water/fuel/obstacle objects
incident/<id>/model/weather retained wind(z), T, RH, density altitude, forecast
ac/<callsign>/pos stream lat lon alt crs spd, 2 Hz (IP) or beacon rate (LoRa)
ac/<callsign>/vital retained battery/fuel, endurance_min, bingo_in_min, water_kg, temps, link RSSI
ac/<callsign>/mech retained motor/engine health, vibration, GPS fix, IMU, actuator faults, warnings[]
ac/<callsign>/state retained mode: transit / holding / dipping / inbound / dropping / RTB / landed
ac/<callsign>/card retained current tactical drop card from CCR (CCR → aircraft)
ac/<callsign>/ack event card accepted / rejected / completed with impact estimate
ccr/global/options retained planner A, planner B, referee result, status (proposed/approved)
ccr/tactical/<callsign>/options event per-cycle A/B cards and referee margin
ccr/commander/decision event approve / swap / override with text (tablet → CCR)
site/dip/<id> site/fuel/<id> site/helispot/<id> retained capacity, stock, open/closed, approach, last
used
request/designator/<station> event coded request with bearing and crew id
video/<callsign>/<cam>/meta retained stream URL, codec, resolution, current gimbal pose, priority
video/<callsign>/<cam>/detections stream analytics output: boxes, classes, temps, geo-registered
sys/link/<callsign> retained which links are up, latency, packet loss
sys/relay/<surveyor>/heard retained stations heard (coverage)
```

All topics are prefixed by the incident id so two incidents on one broker never mix, and every payload carries a UTC timestamp, the producing node, and a quality flag. QoS 1 for state and cards, QoS 0 for position and detection streams. Retained topics are what a late-joining tablet or a restarted service reads to catch up in one subscription.

03

The mission flow, message by message

Phase 1 — Sector assignment

1. The Commander draws or accepts a sector on the tablet: `incident/<id>/sector/1` with the polygon, priority and the assigned surveyor.
2. The surveyor's mission service subscribes to its sectors, generates an orbit or lawn-mower pattern inside the polygon at the altitude that gives the required ground sample distance, and uploads it to its own flight controller (MAVLink). It publishes `ac/SURV-1/state = surveying`.
3. Video from the surveyor's thermal and EO cameras starts streaming at the highest priority; `video/SURV-1/thermal/meta` carries the stream URL for the Commander's wall and for analytics.

Phase 2 — Detection

4. The analytics service on the command node (Jetson-class or the ground workstation) consumes the thermal stream, geo-registers each frame with the surveyor's pose from `ac/SURV-1/pos` and gimbal state, and publishes per-frame detections to `video/SURV-1/thermal/detections`.
5. The tracker turns detections into model objects: a new `model/hotspot/H7` (SAR: a warm body candidate; fire: a spot fire), or an update to `model/fire/F1`'s polygon. First-seen, growth and confidence are maintained here.
6. A new or materially changed object is an event; CCR subscribes to `model/#` and treats it as a re-plan trigger.

Phase 3 — Allocation and tasking

7. Both planners read the model, the aircraft `vital` and `state` topics, and the `site/#` stock, and publish their option sets to `ccr/global/options`; the referee adds its result. The tablet renders both; the Commander's tap goes to `ccr/commander/decision`.
8. On approval, CCR publishes a tactical card to each tasked aircraft's `ac/<cs>/card`: target object id, drop line or search point, approach, release height, dip site, abort point, and the envelope inside which the aircraft may act without a new approval.
9. The aircraft's mission service converts the card to a MAVLink mission or guided commands, acknowledges on `ac/<cs>/ack`, and reports `state` transitions as it flies it. Terminal guidance runs on board; the card only says where to go, not how to close the last metres.
10. On completion the aircraft publishes an ack with its own impact estimate (release time, position, mass); the surveyor's next frames confirm the effect through steps 4–6, and the loop repeats.

Phase 4 — Verification (SAR)

11. For a SAR hot spot the card is a verify task: fly to the point, put the zoom and IR camera on it, stream at high priority for 30 s. The analytics service and the Commander both see the stream; the Commander's one-tap verdict (person / animal / false) is written back to `model/hotspot/H7/verified` and CCR either escalates (dispatch, mark for ground team) or clears it.

04

Vital and mechanical telemetry — what CCR watches and why

CCR does not plan on raw MAVLink. A per-aircraft vital service on the companion computer condenses the firehose into a small retained document that is updated every second and that the planners can reason about directly:


```
{"cs":"SUPP-2","t":"...","energy":{"kind":"battery","pct":41,"v":22.1,"wh_rem":310},"endurance_min":9
.5,"bingo_in_min":4.0,"bingo_site":"PAD-1","water_kg":0,"payload_state":"empty","temps":{"motor_max":
71,"esc_max":64},"link":{"ip":"up","lora":"up","rssi":-78},"health":"ok"}
```

Field	Computed from	What CCR does with it
endurance_min	Energy remaining ÷ measured consumption over the last 60 s, corrected for payload mass and wind	The hard limit on any card; a card that would end with less than reserve is never generated
bingo_in_min	endurance minus the flight time to the nearest usable recovery site (`site/#` with open status) minus reserve	When it reaches zero the referee forces an RTB option ahead of any task; the Commander is told, not asked
water_kg / fuel_kg	Load cell on the hook or bucket valve state; fuel flow or tank sensor	Whether the aircraft can take another drop or must dip; which dip site is in reach
temps, vibration, faults	ESC / engine monitor, IMU statistics, flight-controller warnings	Degraded health lowers the aircraft's capability score in both planners; a critical fault removes it from allocation and raises an RTB
link status	Companion computer's own view of each radio	Planner B refuses to send an aircraft behind terrain without surveyor relay coverage; the card carries a lost-link behaviour

Sites and stock

Fuel points, dip sites and helispots are stations on the position network, so their beacons already carry litres available and open/closed. A logistics service keeps `site/#` current from three sources: the beacon's own report, the fuel truck's beacon (its stock moves with it), and aircraft acks (every fill at a dip site decrements its stock; every refuel decrements the point). CCR's planners read these as capacities with location, so “which dip site” and “which fuel point still has 400 L” are ordinary planning variables, and a site that runs dry closes itself in the model before an aircraft is sent to it. The Commander sees stock on the map and can override a status with one tap.

Bingo, worked

SUPP-2 is inbound for a third drop on F1 with 41 % battery. Its vital service computes 9.5 min endurance; the nearest open pad is PAD-1, 3.2 min away; reserve is 2.5 min; bingo_in_min = 4.0. Planner A's card wants the drop (2.5 min) and a return to the dip site; Planner B's card wants the drop and an immediate RTB to PAD-1. The referee's hard rule sees that A's card ends below reserve and discards it; B's card is presented as a consensus-by-elimination with the line “bingo in 4.0 min after drop → PAD-1”. When bingo_in_min hits zero without a card in flight, the referee issues the RTB itself, publishes it to the card topic and to the Commander as a notice, and the planners re-plan the fire with one fewer aircraft. Nobody had to watch a battery gauge.

05

Multi-channel video

Two consumers, one source

Every camera stream has two readers that must never interfere with each other: the human consumer (the Commander's video wall and tablet, air attack, the SAR chief) who wants the raw picture with the lowest latency and no processing in the way, and the machine consumer (the analytics service feeding the fire state model) who wants every frame with its pose. The architecture is therefore: each aircraft encodes once, the ground station receives once, and a stream router fans out — one copy to the wall unmodified, one copy to analytics, one copy to the recorder.

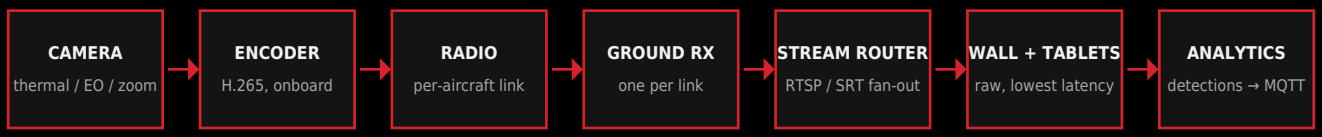


Figure 1 — one encode, one receive, three consumers. The analytics branch never adds latency to the human branch.

Channel plan

Source	Streams	Priority	Bitrate (H.265)	Notes
Surveyor	Thermal 640×512 @ 30; EO 1080p @ 30; optional zoom	Always on, highest	2 + 6 Mbit/s	Thermal is the model's primary input; EO is for humans
Each assistant drone	Downward EO/NIR; small thermal	On task (inbound/dropping/verifying); idle at 1 fps otherwise	1–4 Mbit/s	Human watches the drop; analytics confirms release and target lock
Each helicopter	Nose EO/IR turret; bucket camera	On task; bucket cam only on dip and drop	4–8 Mbit/s	Pilot-selectable downlink in the piloted configuration
Ground designator (optional)	Helmet / handheld cam	On request	1 Mbit/s	Lets the Commander see what the crew leader is pointing at

With one surveyor and four assistants the aggregate at the ground station is on the order of 15–30 Mbit/s with everyone active, well inside what the radios below carry, and the priority scheme keeps idle aircraft at a trickle so the surveyor's streams never starve.

Radio choices

Tier	System	Band	Range / throughput / latency	Fit
Demonstration	WFB-ng (open-source wifibroadcast) with OpenIPC cameras or a Raspberry Pi / Jetson encoder	5.8 GHz (2.4 GHz option), Part 15	Several km with directional ground antennas; 10–25 Mbit/s; ~40–80 ms; carries MAVLink on the same link	One ground receiver per aircraft, cheap, fully under our control; the PX4 and OpenIPC projects document the ground station
Demonstration, turnkey	CubePilot Herelink Blue; SIYI HM30 / FT24	2.4 GHz; 5.1–5.8 GHz	12–15 km / 10 Mbit/s; 15–30 km / 8 Mbit/s; ~110 ms	Integrated video + telemetry + RC per aircraft; fine for X650-class assistants
Operational, industrial	Microhard pDDL / p900; Doodle Labs Smart Radio	900 MHz, 2.4 GHz (1.4 GHz variants are not usable unlicensed in the U.S.)	20–60 km / 12–15 Mbit/s / ~90–110 ms; AES	IP radio, mesh capable; the surveyor can relay assistants on the same network
Operational, mesh	Silvus StreamCaster (SC4200 / SL5200 class) MANET	L / S / C band, licensed or coordinated	80 km+ LOS / 100 Mbit/s+ / ~50 ms; AES-256; single radio for video, C2 and telemetry	The helicopter-class answer; Silvus markets exactly this single-radio UAV configuration and airborne ISR relay

Two cautions from the research: consumer FPV systems (DJI O4, Walksnail, HDZero) give superb pictures to goggles but are closed, single-viewer links with no clean way to fan the stream out to a wall and an analytics box; and digital video does not degrade gracefully — when the link margin is gone the picture freezes rather than snows — so the priority scheme and the surveyor relay are not luxuries. OpenIPC/WFB-ng is the demonstration choice precisely because it is an open IP link that lands the stream as ordinary RTP on the ground station where it can be routed.

The human branch

- Video wall: every active stream in a grid, surveyor thermal largest, with the model overlay (fire polygons, hot-spot ids, aircraft, crews) drawn on top from MQTT so the Commander sees the raw picture and the machine's reading of it together, and can toggle the overlay off.
- Tablet: the stream for whichever aircraft the current CCR card concerns, picture-in-picture over the map; the two option overlays in blue and amber.
- Air attack / pilots: the surveyor thermal downlinked to the cockpit tablet in the piloted configuration, which is what Rain and Sikorsky showed crews in 2025.
- Recorder: all streams and all MQTT, time-aligned, for replay.

The machine branch

- Geo-registration of every thermal frame with the pose message nearest in time (sub-50 ms alignment matters; the timestamps come from GPS on both ends).
- Detection and tracking publish to `video/<cs>/<cam>/detections`, and the tracker maintains the model objects.
- Drop assessment: the frames after an ack are compared with the frames before; cooling area and residual hot spots are written to the fire object and to the ack's effect field, which is how CCR learns whether a second drop is needed.
- Assisted decision: nothing in the machine branch commands an aircraft. It writes to the model; CCR reads the model; the Commander approves. Video analytics is an input to judgment, not a substitute for it.

06

Demonstration build and what to measure

- Broker and services: Mosquitto plus the gateway, tracker, logistics, vital and stream-router services on one ground laptop; the analytics on the Jetson Orin. Same stack that already runs the property's telemetry, so the operating habits transfer.
- Links: LoRa beacons on everything; mLRS or WFB-ng MAVLink per aircraft; WFB-ng video with one receiver per aircraft and a directional antenna toward the demo field.
- Measure: message latency sector → surveyor → detection → model → card → ack (target under 10 s end to end); position-network packet success with and without the relay; video latency wall and analytics; time from a candle being lit to a card being approved; one forced bingo and one forced lost-link to show the recovery behaviour on the wall.

Sources: PX4 documentation, “Video Streaming Data-link using WiFi in Raw Mode (WFB-ng)”; OpenIPC ground-station documentation; Moneypro Group, “7 Best Long Range Video Transmitter Radio UAV Systems: 2026 Industry Guide” (Aug 2026; vendor figures); Silvus Technologies unmanned-systems pages (2026); Oscar Liang / UAVModel FPV system comparisons (2026); Rain / Sikorsky demonstration notes (2025); ArduPilot mLRS documentation. Bitrates and latencies are design targets or vendor claims and should be measured on the demonstration hardware.