Trials of Mobile-Connected Drones and the Benefits of Operator-Managed Licensed Spectrum

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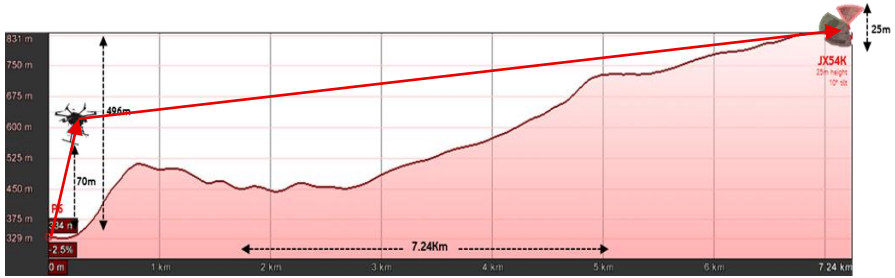
Target Use Cases

Use Case	Cellular Connectivity Benefits	Is Cellular Essential ?	Cellular Frequency Bands
Enterprise Use Cases			
– Linear Asset Inspection	Telemetry Video Streaming / Upload Secure Command and Control	YES	Both low and high bands (for coverage and capacity)
– Time-critical Logistics	Telemetry Secure Command and Control	YES	Primarily low band (for coverage)
UTM Support Communication Service Provider	Telemetry Secure Command and Control Drone Identification Network-based Geo-location	YES	Primarily low band (for coverage)
Temporary Cellular Coverage	Relay backhaul	YES	All bands (for flexibility)
Tower Inspection & Monitoring	Video Streaming / Upload	NO	High bands (for capacity)

Temporary Coverage Extension

- **Drone-mounted cellular relays**
  - The relay **overcomes local shadowing** to provide a better propagation path to the nearest macrocell
  - A **tethering system** provides power and control for extended flight times
  - Can use macrocells from **any MNO** whilst still activating as a Vodafone or MVNO cell
- **Use Case : Temporary Coverage**
  - **Emergency Services Network** (ESN) support
  - **Local cell outage** due to fire/storm damage etc.
  - **Special events** (e.g. festivals) in locations with poor coverage



Benefit of Licensed Spectrum

- Seamless experience for customers
- Allows use of existing infrastructure for backhaul
- Allows use of low-cost commodity hardware

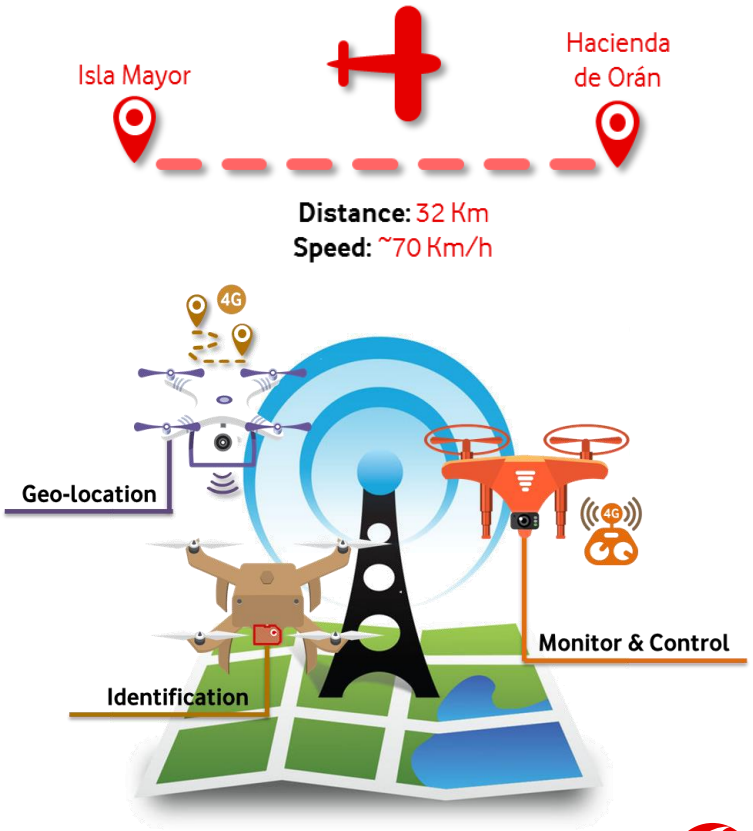
Drone Operations | The role of cellular

Licensed cellular can help address emerging regulatory requirements for drone operations

- **Compliance with geographical limitations** set by National Aviation Authorities
  - A licensed cellular based solution is an effective way to enable geographic limitation services as the location of the drone can be remotely verified in the network and compared against a reference database of restricted areas.
- The drone, the operator and the nature and purpose of the drone operation should be **easily identified** where required
  - A licensed cellular solution is an effective way to enable drone identification / authorisation services (where required) as identity verification and management are already key components of a licensed cellular service
- The **safety of third parties** on the ground and also other airspace users must be ensured
  - Licensed cellular can provide flight configuration, beaconing and remote intervention, monitoring the drone whilst in flight in order to receive any alerts
- Drone operators must be able to **react to interrogations** from enforcement entities
  - Lawful intercept already exists for licensed mobile services, designed to protect national security and public safety.

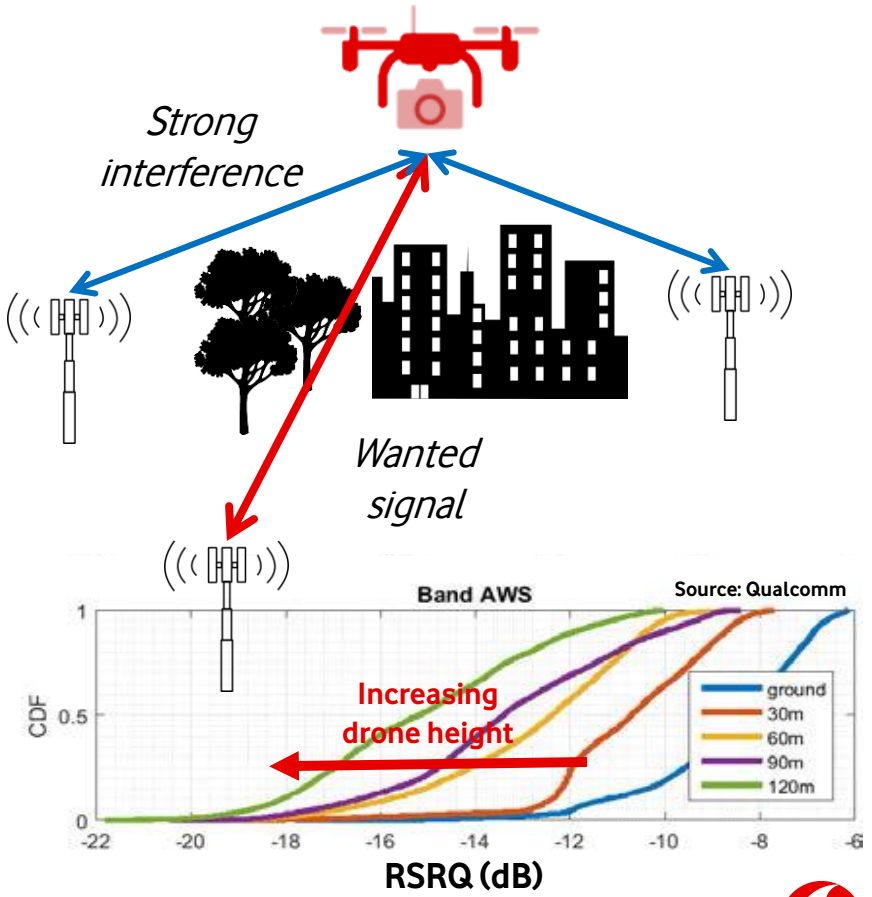
UTM Support | Seville Demo October 2017

- Vodafone have an ambition to be the **communications service provider** (CSP) for UTM
  - But no ambition to provide the UTM itself
- UTM demo undertaken to demonstrate capabilities
  - **Command, control and telemetry** via 4G cellular
  - Drone **identification** to the UTM
  - Network-based drone **location estimation** to complement GPS reports
  - **Continuous connectivity**
- Drone was equipped with a commercial 4G modem
  - Low-cost commodity hardware with **no special capabilities**
- Drone geo-location using Vodafone's **Radio Positioning System** (RPS)
  - RF Fingerprinting technique, relying on "honest" drones for calibration
  - Radio measurement matching achieved using Artificial Intelligence (AI)
  - 2D only, RPS cannot reliably estimate drone height
  - Royalty free, any operator can implement this



Interference Management

- The cellular network does **not need** to be significantly **modified** to support drones
  - Hence the interference **from** cell sites will not change
- But drones fly have **better propagation** to nearby cell sites than a normal phone
  - Resulting in **increased uplink interference** levels
  - This will affect **all cellular users**, not just drones
- To manage this, Vodafone are testing a **drone-specific radio management optimisations**
  - The drone SIM is tagged to **identify it as a drone** to the base-station, rather than a normal phone or device
  - The uplink power control **parameters signalled** to the drone are then **modified** to reduce the interference
  - The drone modem can also be **moved onto a different frequency band** to avoid interference to sensitive receivers



Conclusions

- Many drone use cases benefit from **cellular connectivity**
- But the business case does **not** currently support:
  - Significant network infrastructure enhancements beyond current plans
    - i.e. no new bands, sites or antenna configurations specifically to support drones
  - Use of specialised modems supporting non-3GPP frequency bands
- Hence
  - Drones need to use **standard commodity IoT modems**, albeit conforming to minimum requirements
  - Cellular operators need to make **best use of existing assets and frequency bands**
- This requires as **few restrictions as possible** on which frequency bands can be used and where
  - Low frequency bands (700 MHz, 800 MHz) are best for coverage
  - High frequency bands (1800 MHz, 2100 MHz, 2600 MHz and higher) are best for capacity
- Cellular operators have techniques to **mitigate interference** from drones into other users
  - Drone-specific uplink power control will **reduce excess interference**
  - Use of specific frequency bands by drones can be **prohibited in some areas** (e.g. to protect radio astronomy sites)