# Understanding Drone Communication Protocols

Presented by –
Jalaj
@ NFSU x BSF
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Cybersecurity Enthusiast
Various roles –
- Security Operation Ceter Analyst (SOC)
- Detection and Response Team
- Security Engineer
- Researching on Defensive AI

Reach out to me at ..

Linkedin.com/in/teamblue

# Agenda

- ❑ - Introduction to Drone Communications
- ❑ - RF (Radio Frequency) Protocols
- ❑ - WiFi Protocols
- ❑ - LTE and Cellular Protocols
- ❑ - Comparisons, Integrations, and Challenges
- ❑ - Future Trends and Conclusion
- ❑ - Q&A

# Why Drone Communications Matter

- ❖ Drones (UAVs) rely on reliable, low-latency links for control, telemetry, and payload data.
- ❖ Key requirements: Range, bandwidth, security, interference resistance.
- ❖ Applications: Consumer (photography), Industrial (inspection), Military (surveillance).
- ❖ Protocols enable VLOS (Visual Line of Sight) and BVLOS (Beyond Visual Line of Sight) operations.

- ❑ Different missions need different trade-offs: low latency vs. high throughput vs. long range.
- ❑ Urban vs. rural RF conditions and regulations strongly influence design.

# Overview of Drone Ecosystem

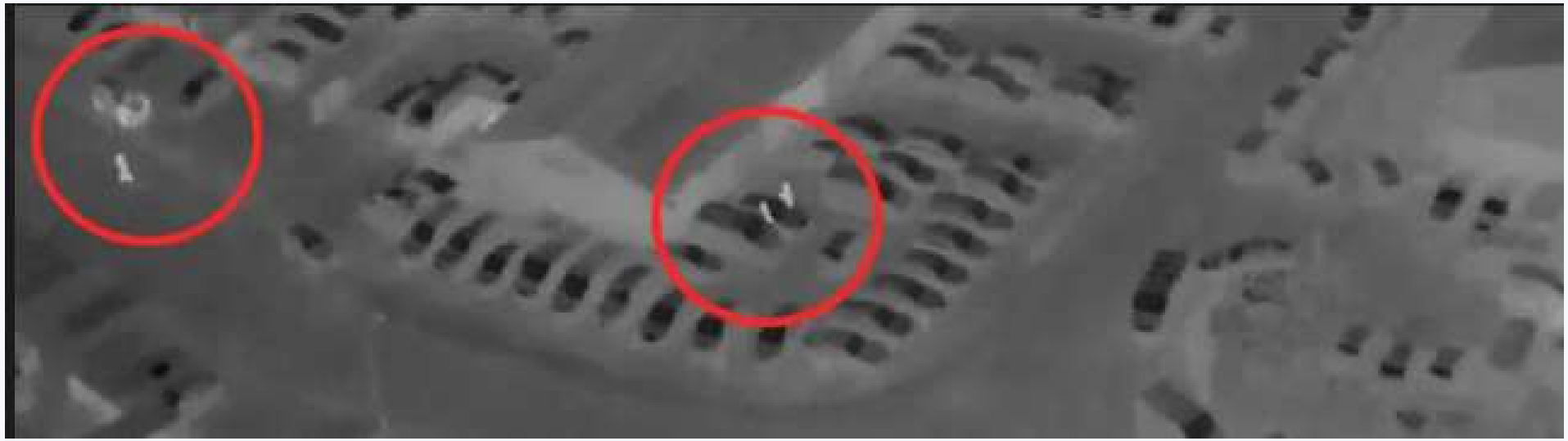
- Components: Ground Control Station (GCS), UAV, Payload (e.g., camera).
- Communication Types: Command & Control (C2), Telemetry, Video Streaming.
- Challenges: Spectrum congestion, signal attenuation, regulatory compliance (e.g., FAA rules).

# Communication Architecture

- Direct: Wi-Fi/RF between UAV and GCS (line-of-sight).
- Backhauled: LTE/5G via carrier network for BVLOS scenarios.
- Hybrid: primary + fallback links for resilience.

# Key Requirements

- Latency: sub-50 ms desirable for control; higher is ok for non-critical data.
- Throughput: HD video needs Mbps; telemetry needs kbps.
- Security: encryption + auth; Resilience: redundancy + monitoring.



# Frequency Spectrum Basics

- 2.4/5.8 GHz ISM used by Wi-Fi and many RF control/FPV links.
- Sub-GHz (e.g., 868/915 MHz) penetrates better, trades bandwidth.
- LTE uses licensed bands; availability and rules vary regionally.

# Wi-Fi Overview

- Based on IEEE 802.11; easy hardware availability and integration.
  - Standards: 802.11a/b/g/n/ac/ax (WiFi 6).
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- Common in consumer drones for control + video downlink.
- Range: 100-500m outdoors, extendable with boosters.

# Wi-Fi Advantages

- High throughput supports HD/4K video and rich telemetry.
- Commodity chipsets, good tooling, and rapid updates.
- Simple pairing with tablets/phones for GCS apps.
- Aerial photography near operator; campus/industrial inspections.

# Wi-Fi Limitations

- Shorter functional range vs RF/LTE in many environments.
- Congestion/interference in ISM bands (urban multipath).
- Power draw rises at the edge of coverage.

# RF (Radio Frequency) Protocols

- Frequency Bands: 2.4 GHz (ISM band), 5.8 GHz for video, 433/915 MHz for long-range telemetry.
- Traditional RC control plus modern digital RF links.
- Modulation: FM, AM, Spread Spectrum (e.g., FHSS for interference avoidance)
- Power: Typically, 100mW to 1W, regulated by FCC/ETSI.
- Range: Up to 10-50 km with directional antennas.

# RF Advantages

- Very low Low latency (<22ms), reliable in noisy environments.
- Better range with proper antennas (esp. sub-GHz).
- Lower overhead vs Wi-Fi; robust in clean RF environments.

# RF Limitations

- Lower video bandwidth compared to Wi-Fi/LTE.
- Susceptible to interference without hopping/spread spectrum.
- Regulatory power limits and duty cycles apply.

# RF Use Cases

- FPV racing/freestyle where low latency is critical.
- Rural/remote telemetry/control; separate video downlink.
- Emergency ops with directional antennas to extend reach.
- Low latency (<22ms), reliable in noisy environments.

# LTE/Cellular Overview

- Leverages carrier networks (4G/LTE/5G) for wide-area coverage.
- Enables BVLOS (beyond visual line of sight) where permitted.
- 4G LTE: Bands vary (700-2600 MHz), global coverage.
- Latency: 10-50ms, throughput up to 100Mbps+.
- Range: Cellular tower-dependent, virtually unlimited.

# LTE Advantages

- Wide coverage (where networks exist); easy backhaul to cloud.
- Carrier-grade security/QoS; strong uplink for compressed video.
- Supports centralized fleet operations.
- Multi-SIM: Bonding for redundancy.
- Applications: Delivery (e.g., Amazon Prime Air), surveying.
- 5G Integration: URLLC (Ultra-Reliable Low-Latency) for <1ms latency.

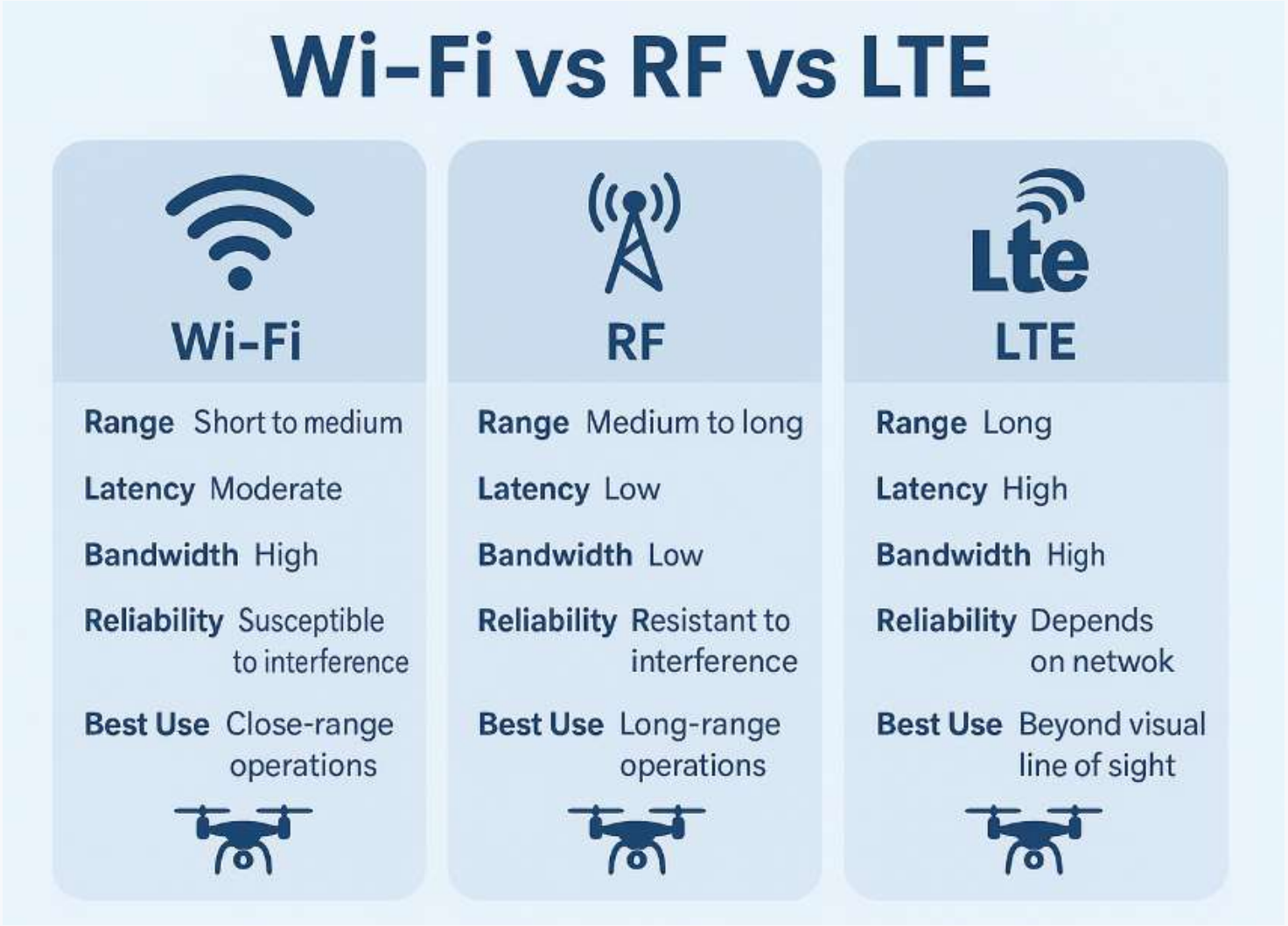
# LTE Limitations

- Carrier dependency, SIM costs, and sometimes airborne restrictions
- Variable latency/handover events; tunnel/canyon dead zones.
- Need careful firewall/VPN posture for enterprise.

# LTE Use Cases

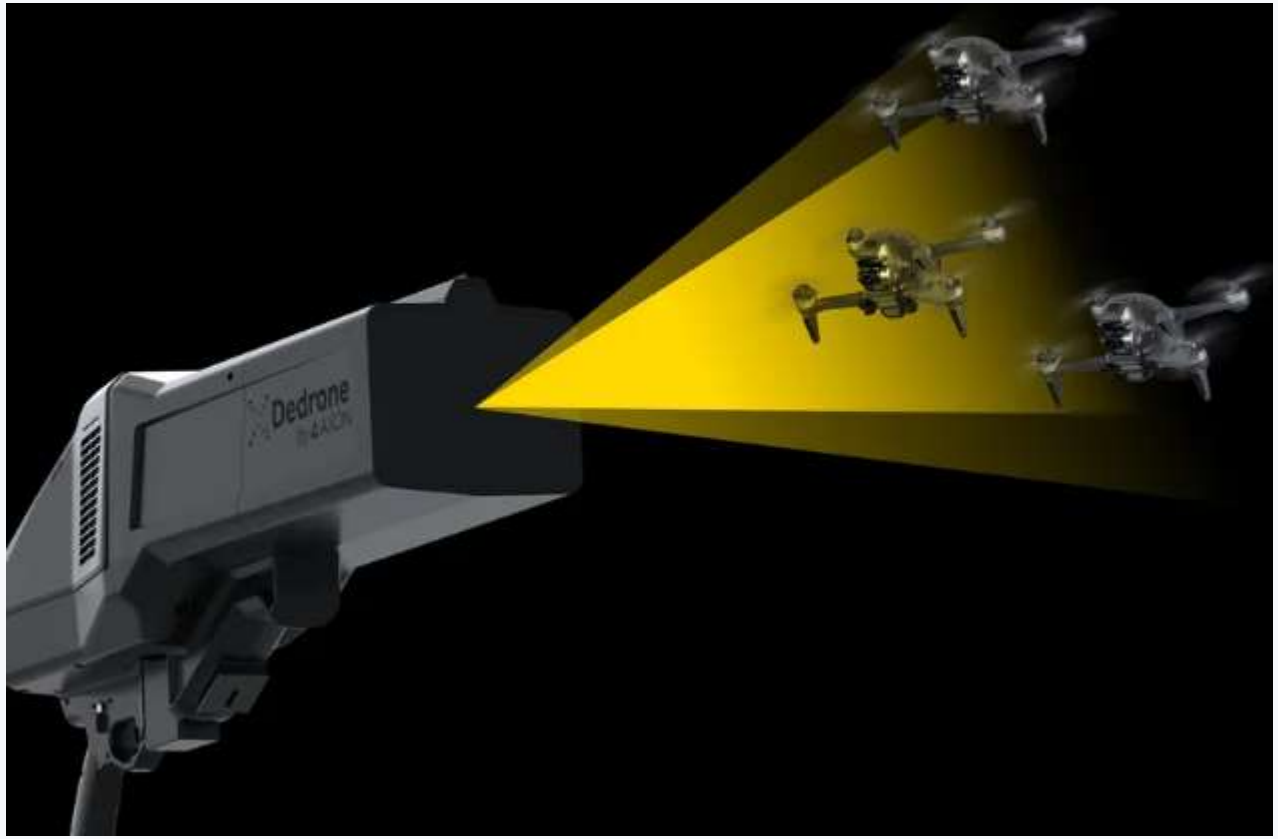
- Delivery corridors, long linear inspections (pipelines, rails).
- Public safety: live feeds to command centers.
- Fleet management with centralized control rooms.

# Protocol Differences (At-a-Glance)



# Anti-Jamming & Resilience

- Spread spectrum/frequency hopping; adaptive power and channel.
- Diversity/MIMO antennas; RF filters; careful placement.
- Redundant links (e.g., RF primary, LTE fallback).



# Challenges Across Protocols

- Interference/Jamming: RF/WiFi vulnerable; LTE better with error correction.
- Security: RF sniffing, WiFi spoofing, LTE SIM cloning.
- Regulations: Spectrum allocation, privacy (e.g., drone ID).
- Power/SWaP: Critical for flight time.

# Hybrid Architectures

- Dual links: RF for C2 + Wi-Fi/LTE for video and data.
- Automatic failover based on link KPIs (RSSI/SNR, loss, jitter).
- Health monitoring and alerts integrated in GCS.

# Future: 5G & Beyond

- ❑ URLLC + network slicing for dedicated drone lanes.
- ❑ Edge compute offload for perception and routing.
- ❑ 6G: Terahertz bands for ultra-high bandwidth.
- ❑ AI-Optimized Links: ML for adaptive modulation.
- ❑ Satellite + LTE: LEO constellations (Starlink) for global coverage.
- ❑ Quantum-Safe Encryption: Post-quantum for all protocols.

# Summary & Key Takeaways

- RF: Reliable for control, limited data.
- WiFi: Convenient for short-range, video-heavy.
- LTE: Scalable for long-range, but coverage-dependent.
- Choose based on mission: Hybrid often best.

# Thank You

Have any questions ?
Reach out …

- Mob – 8851458452
- LinkedIn – Linkedin.com/in/teamblue

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