IEEE VTS

Connecting the Mobile World

WEBINAR SERIES ON ADVANCED MOBILITY

UAV communications standards

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UAV Communications Standards

- Motivation
- UAV communications requirements
- Communication standards for UAVs
- Future directions
- Conclusions

UAVs are here to revolutionize the World!

- Traffic:
  - Congestion
  - Accidents
  - Commute Times
- Environment:
  - Pollution
- Emergency Services:
  - Response Time
- Business:
  - Package Delivery
- Critical Infrastructure:
  - Monitoring
- Society:
  - Safety
  - Security

UAV Technology Readiness Today

- Economics: High costs of service (capital and battery costs)
- Weather: Adverse weather can affect aircraft operations and performance
- Air Traffic Management: potential stress to the current ATM system due to high density
- Battery Technology: Charging times and weight
- Impact: Energy and environmental impacts (e.g. noise)

UAV communications requirements

- Self-Organization
  - Ad-hoc networks in the sky
  - Addressing, neighbor discovery, network formation, path planning and routing
  - IEEE P1920
- Spectrum Utilization
  - Commercial UAVs operated in the ISM bands (900MHz, 2.4GHz and 5.8GHz)
  - Maybe spectrum sharing in the future:
    - Opportunistic Spectrum Access: UAVs are secondary unlicensed users and utilize the spectrum gaps of licensed users
    - Competitive Spectrum Access: unlicensed users (spectrum buyers) placing bids for getting spectrum access from single or multiple competing sellers using one of existing spectrum auction
    - Cooperative Spectrum Access: the primary users coordinate with the spectrum seekers (e.g., UAVs) to share with them a portion of their spectrum access
- Communication Protocols

UAV communications requirements

- C2 communications requirements:
  - Controlling UAV flight operations involves four distinct C2 modes
    a) steering to waypoints,
    b) direct stick steering,
    c) automatic flight by UTM, and
    d) approaching autonomous navigation infrastructure

Defined C2 modes KPIs by 3GPP TS 22.125, V17.6.0.

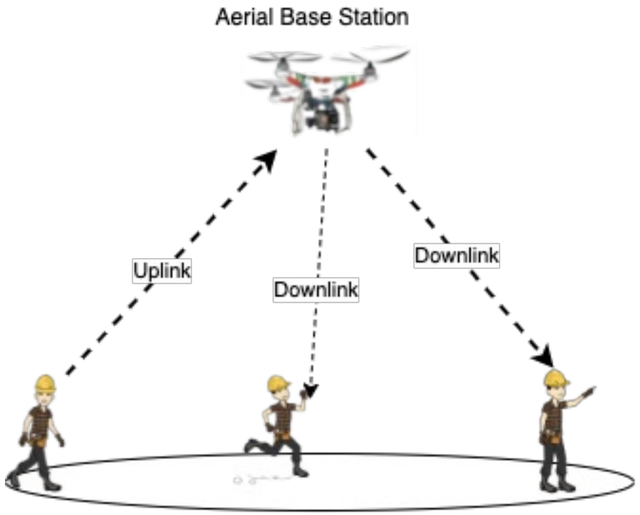
Control Mode	Packet Timing	Maximum UAV Speed	Packet Size	Time Delay	Acknowledgment
Waypoint steering (UAV termination)	Less than 1 second	Up to 300 km/h	100 bytes	1 second	Mandatory
Waypoint steering (UAV origin)	1 second	Up to 300 km/h	84-140 bytes	1 second	Not necessary
Direct stick steering (UAV termination)	40 milliseconds	Up to 60 km/h	24 bytes	40 milliseconds	Mandatory
Direct stick steering (UAV origin)	40 milliseconds	Up to 60 km/h	84-140 bytes	40 milliseconds	Not necessary
UTM-guided autonomous flight (UAV termination)	1 second	Up to 300 km/h	Less than 10 kilobytes	5 second	Mandatory
UTM-guided autonomous flight (UAV origin)	1 second	Up to 300 km/h	1500 bytes	5 second	Mandatory
Approaching Autonomous Navigation Infrastructure (UAV termination)	500 milliseconds	Up to 50 km/h	4 kilobytes	10 milliseconds	Mandatory
Approaching Autonomous Navigation Infrastructure (UAV origin)	500 milliseconds	-	4 kilobytes	140 milliseconds	Mandatory

UAV communications requirements

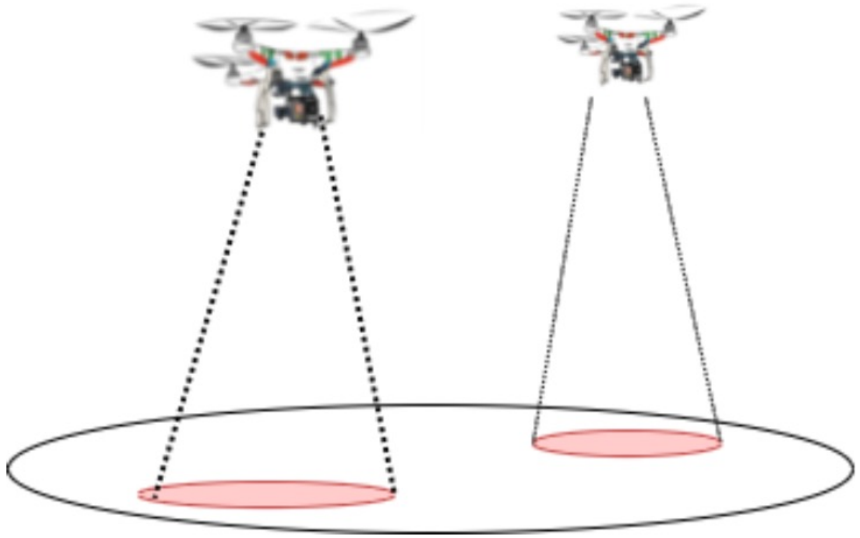
Security requirements

FANET Connection	Security Threats
Connection between client terminals and GCS	Eavesdropping Insider Replay
Connection between GCS and backbone UAV	Eavesdropping Jamming MITM Replay
Connection between backbone UAV and other UAVs in a FANET, or Connection among legitimate UAVs in a FANET	Eavesdropping Jamming MITM Replay
Connection of a FANET with an unknown UAV	Impersonate
Connection to a cloud service from the backbone UAV,other UAVs, or ground devices (GDs)	Data tampering Eavesdropping

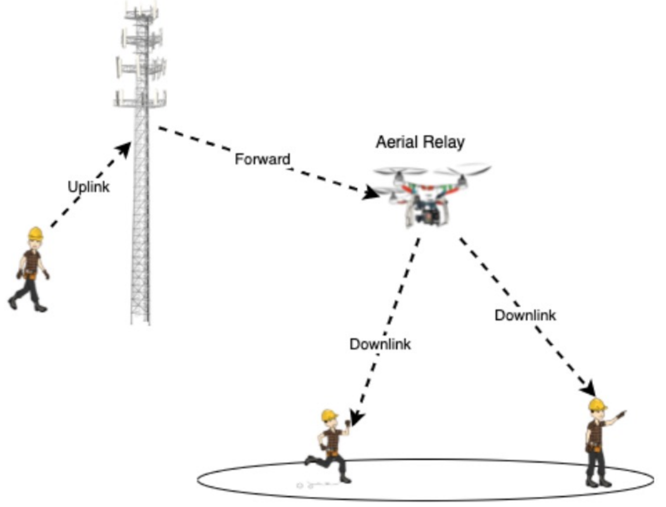
UAV network formations



UAV as aerial base station



UAVs as sensors

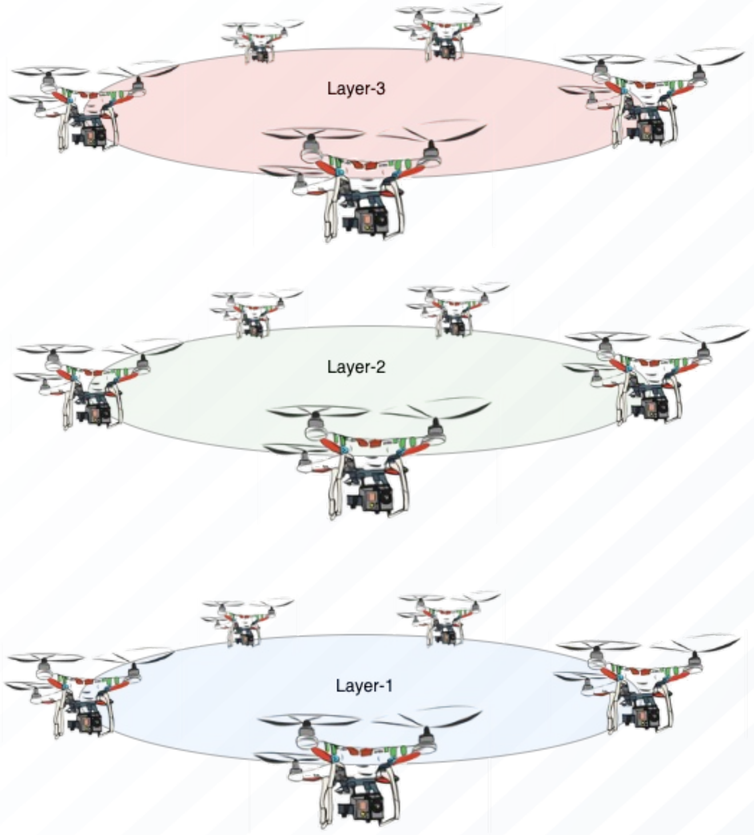


UAV as aerial relay

UAV network formations

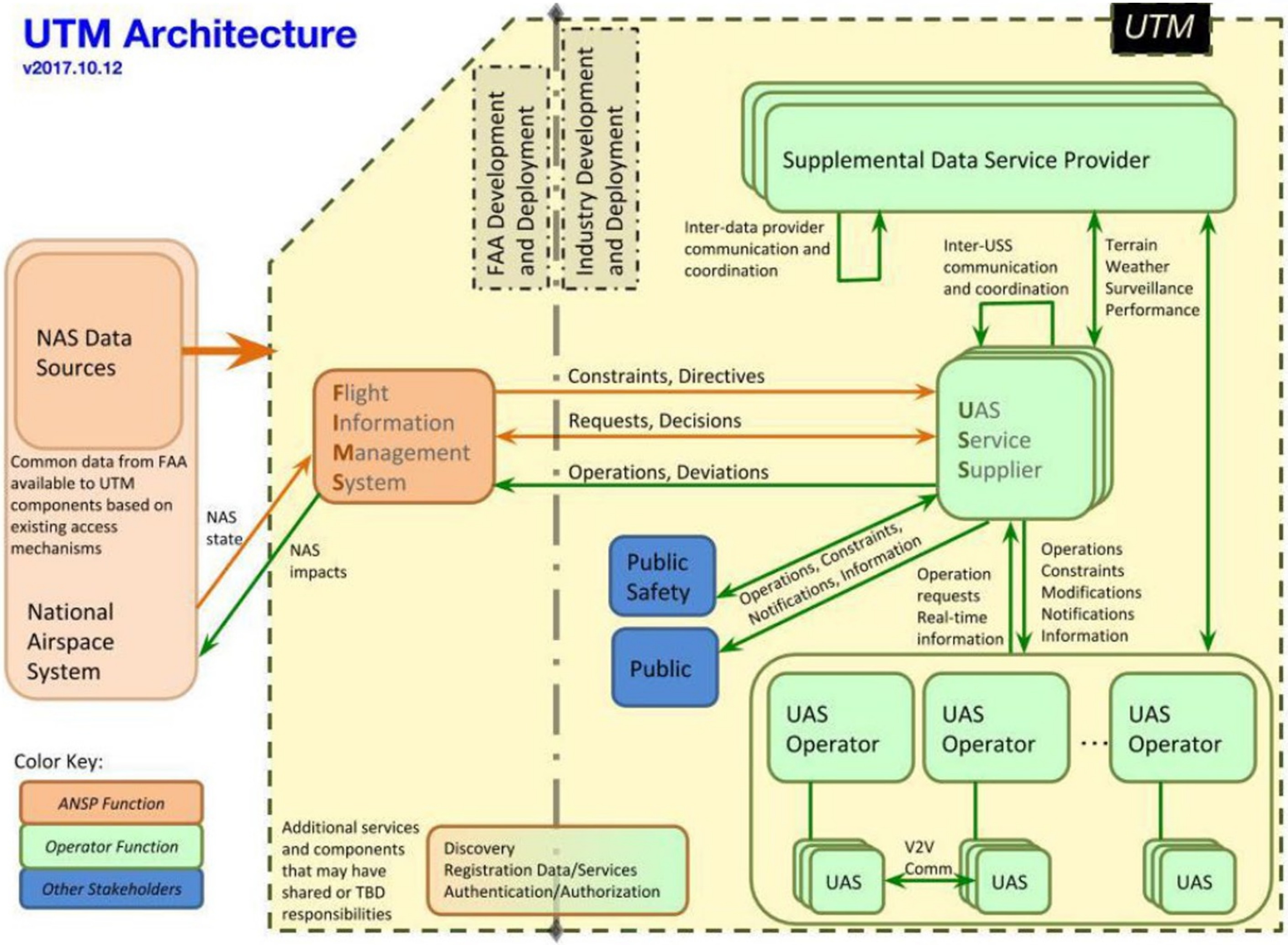
LoS communications

NLoS communications
through ground infrastucture



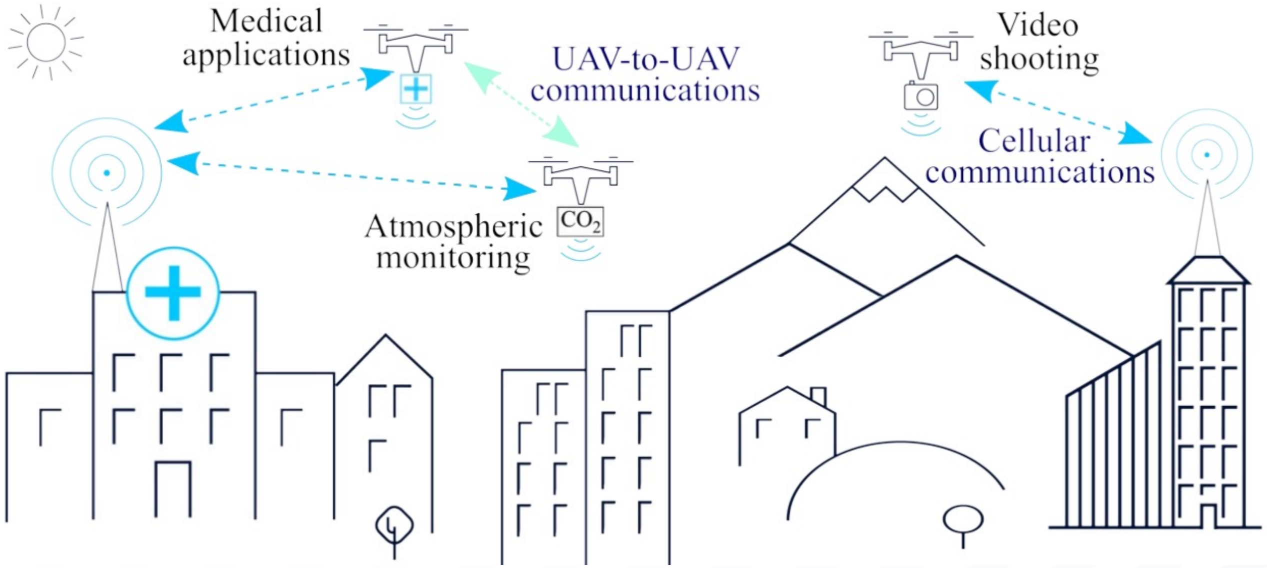
Multi-layered infrastructure

NASA UTM Architecture



UAVs as end-devices

- Mobile networks can handle UAVs as generic end-devices:
  - Handle UAV-generated payload: Similar to current data traffic
  - Handle BVLoS UAV C2: New markets and opportunities
- The idea
  - Seamlessly reuse existing (or soon-to-be-deployed) infrastructures
- However:
  - Performance should be «tuned» to accommodate aerial end devices



G. Geraci, A. Garcia−Rodriguez, and X. Lin, Preparing the ground for drone communications, IEEE ComSoc Technology News, 2019.

UAV corridors

- UAVs unlikely to fly everywhere in an uncontrolled manner
  - We can expect predetermined routes to be defined and regulated
- Ground networks to satisfy ultra-high requirements in specific 3D regions
  - Re-think ground network design, operation, and optimization

UAV corridors: challenges

- V2I vs V2V

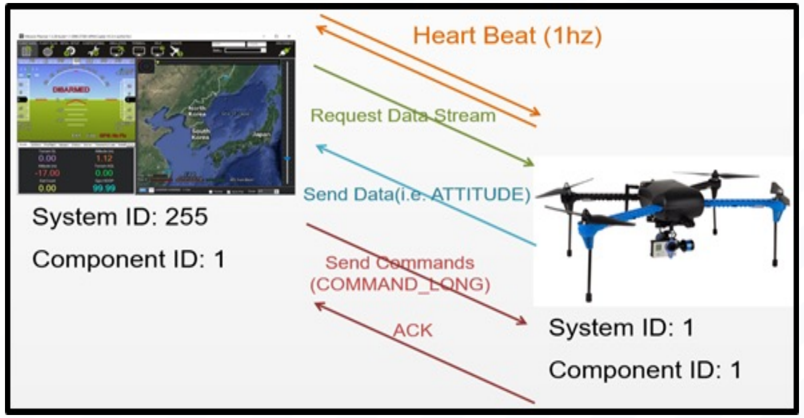
- V2I:
  - Proper infrastructure required
  - 5G/6G?
- V2V:
  - No standards available (maybe an evolution of IEEE 802.11p?)
  - We are working on that! See IEEE P1954 Standardization WG
  - https://standards.ieee.org/ieee/1954/10686/

Communication Architectures for UAVs

- direct links
- satellite UAV networks
- flying ad-hoc and mesh networks
- cellular networks
- Internet of Drones

Direct link communications

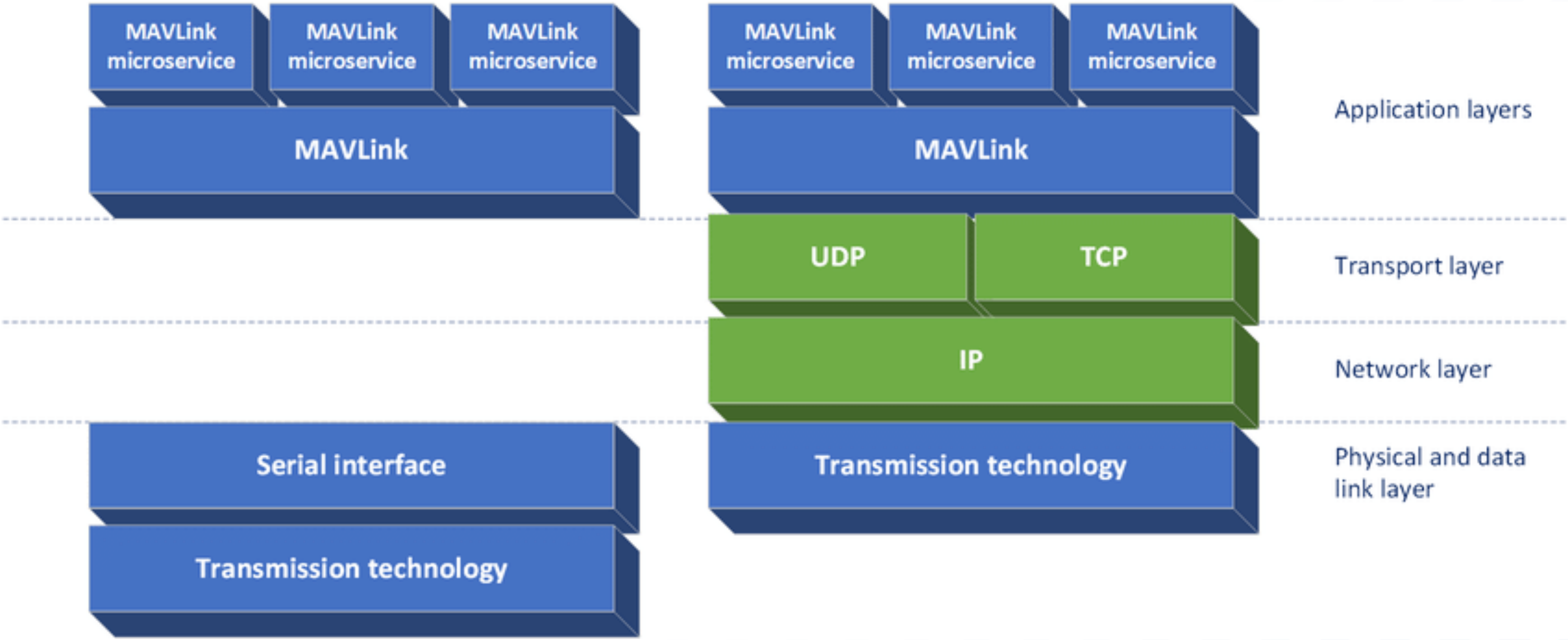
- Direct links between UAVs and ground platforms
  - Typically over an unlicensed band (e.g., the designated ISM band at the frequency of 2.4 GHz)
- Supported by a ground communication node
  - Pilot, remote control unit, Ground Station
- This solution is typically limited to LoS comm.
- Maybe beyond LoS in the future
- Example: MAVLink
  - lightweight messaging protocol for communicating with drones (and between onboard drone components)
  - hybrid publish-subscribe and point-to-point design
  - https://mavlink.io/en/



MAVLink

- MAVLink is a very lightweight messaging protocol for communicating with drones (and between onboard drone components).
- MAVLink follows a modern hybrid publish-subscribe (all autopilot data streams like position, attitude, etc.) and point-to-point design pattern: Data streams are sent / published as topics while configuration sub-protocols such as the mission protocol or parameter protocol are point-to-point with retransmission.
- Messages are defined within XML files.
- Telemetry data streams are sent in a multicast design while protocol aspects that change the system configuration and require guaranteed delivery are point-to-point with retransmission.

MAVLink protocol stack



Stateczny, Andrzej & Gierłowski, Krzysztof & Hoeft, Michal. (2022). Wireless Local Area Network Technologies as Communication Solutions for Unmanned Surface Vehicles. Sensors. 22. 655. 10.3390/s22020655.

Satellite-UAV communications

- Direct links between UAVs and satellites
  - Ku/ka band (WRC 2015)
- Useful for BLoS or large distance
- Disadvantages:
  - Propagation time very large (up to 0.5sec for height < 500m)
  - Payload issues (large satellite antennas)
  - Impacted by weather conditions (rain, fog, etc.)

Ad-hoc and Mesh networking

- Self-organizing infrastructureless networks
  - Built on top of WiFi (IEEE 802.11 a/b/g/n/ax) or WiMAX (IEEE 802.16)
- Nodes/UAVs require routing functionality (FANET)
- Deployment flexibility
- Reduced cost
- Disadvantages:
  - Reliability?
  - Mobility support
  - Topology control
  - Connectivity

Cellular-supported UAV communications

- Communication using cellular mobile networks
  - Licensed spectrum (4G, 5G, 6G)
- UAVs can be «clients» of the cellular infrastructure
  - The cellular infrastructure connects the UAV to the ground station
  - Reliable air-ground communications
- UAVs can be part of the cellular infrastructure
  - Aerial base stations or flying relays (UAV-supported cellular communications)

Internet of Drones

- IoD encompasses protocols that introduce the idea of treating the airspace, especially the low-altitude one, as a limited resource.
- IoD includes several specific activities, such as drones management, flight control, resource optimization, and mission planning.
- It allows for network connection integration between UAVs and the Internet.
- IoD introduces:
  - ad- hoc networking, which ensures coordination between local UAVs
  - Zone Service Provider, which characterizes the backbone of the IoD ground communication infrastructure

UAVs and 3GPP cellular networks

Release 15: Study item

Study on enhanced LTE support for aerial vehicles [TR 36.777]

Signaling protocols for aerial user identification based on subscriptions, reporting of UAV attributes such as location, altitude, and flight trajectory, as well as new measurement reports to tackle air-to-ground interference, interaction with UTM

Releases 16 & 17:

Services and system aspects (SA)

- Rel. 16/17: Remote identification of UAS and support in 3GPP [TS 22.215]
- Rel. 16/17: Study on supporting UAS connectivity, ID, tracking [TS 23.754]
- Rel. 17: Enhancements for UAVs; Stage 1 [TS 22.829]

A. Fotouhi, et al., Survey on UAV cellular communications: Practical aspects, standardization advancements, regulation, and security challenges, IEEE Comm. Surveys & Tuts., 2019.

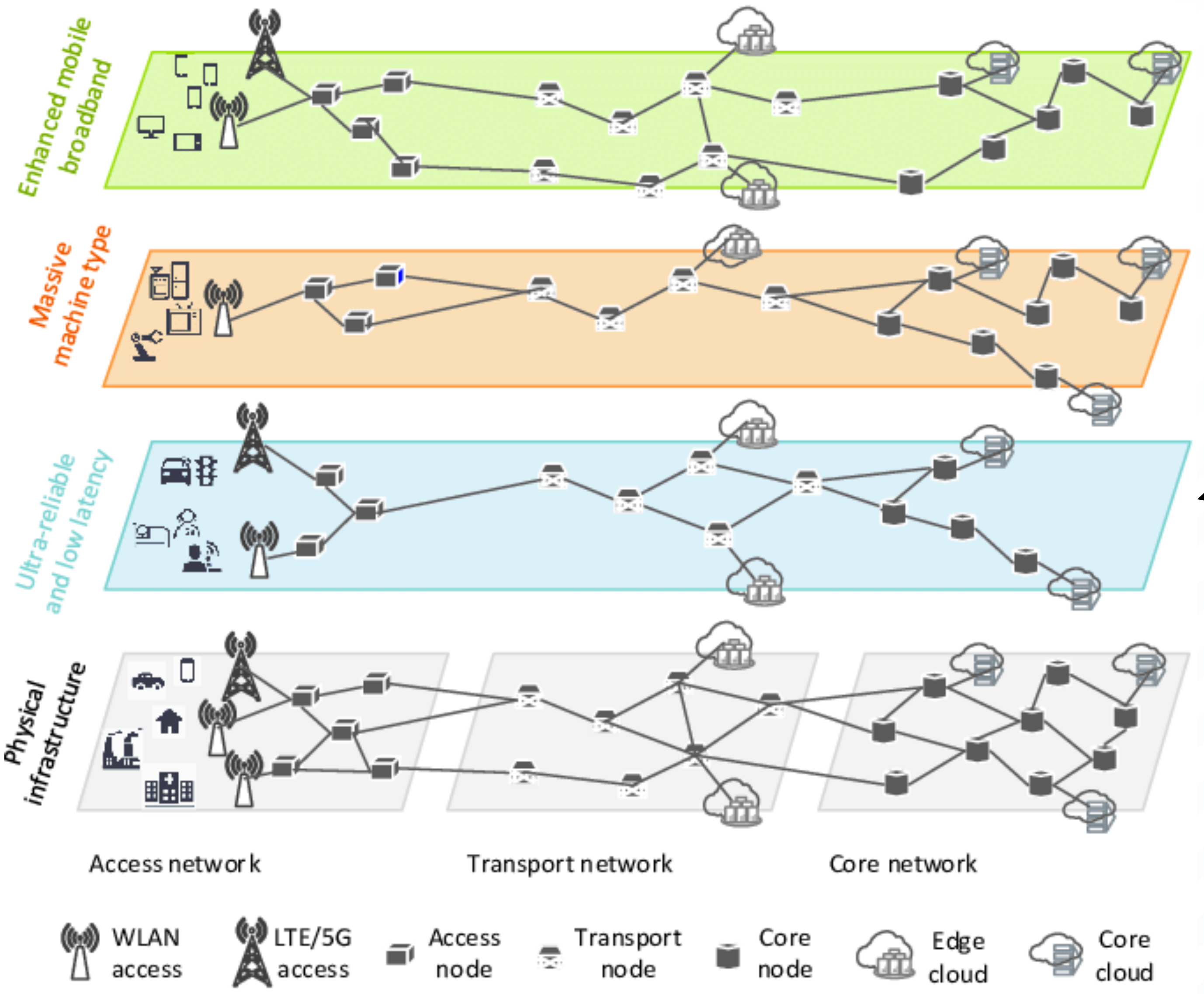
UAVs and 3GPP cellular networks

- Rel-15: Enhanced LTE support for aerial vehicles:
  - to mitigate interference both in the uplink and downlink
  - to address issues related to mobility, and enable identification of UAVs [TR 36.777]
  - channel models taking into account the altitude of UAVs [TR 38.901]
- Rel-16: UAV remote identification [TS 22.825]:
  - requirements and use-cases for remote UAV identification and the corresponding services
  - aimed to enable air traffic control and public safety agencies to access UAV identity and metadata through the UTM for authorization, enforcement, and regulation of UAV operations
- Rel-16: UAV connectivity, identification, and tracking [TR 23.754]:
  - how 3GPP can support communications between the UTM and UAVs
  - to detect and report unauthorized aerial end-devices to the UTM.

UAVs and 3GPP cellular networks

- Rel-17: 5G enhancements for UAVs [TS 22.125 and TS 22.829]:
  - defines new UAV key performance indicators (KPIs) and connectivity requirements in terms of command and control link, data payload, radio access node onboard the UAV (UxNB)
  - UAV constraints on services and network exposure
- Rel-17: Application layer support for UAVs [TR 23.755]:
  - applications for tracking and identification of UAVs
  - impact of UAV service requirements on the application layer
  - UAV-UTM service interactions for managing location, route authorization, and support of group communications
  - considers the reuse in aerial systems of solutions and architectures previously developed for V2X and mission-critical operations
- Rel-18: NR support for UAVs:
  - will investigate enhancements to measurement reports, signaling for UAV multicast and identification based on subscription, conditional handover and new triggering events
  - beam management in FR1 (Frequency Range 1, below 8 GHz), including the use of multi-antenna beamforming and dedicated BS antenna uptilt for UAVs.

5G Network Slicing: A Slice for UAVs?



Customizing a URLLC slice for drone operation?

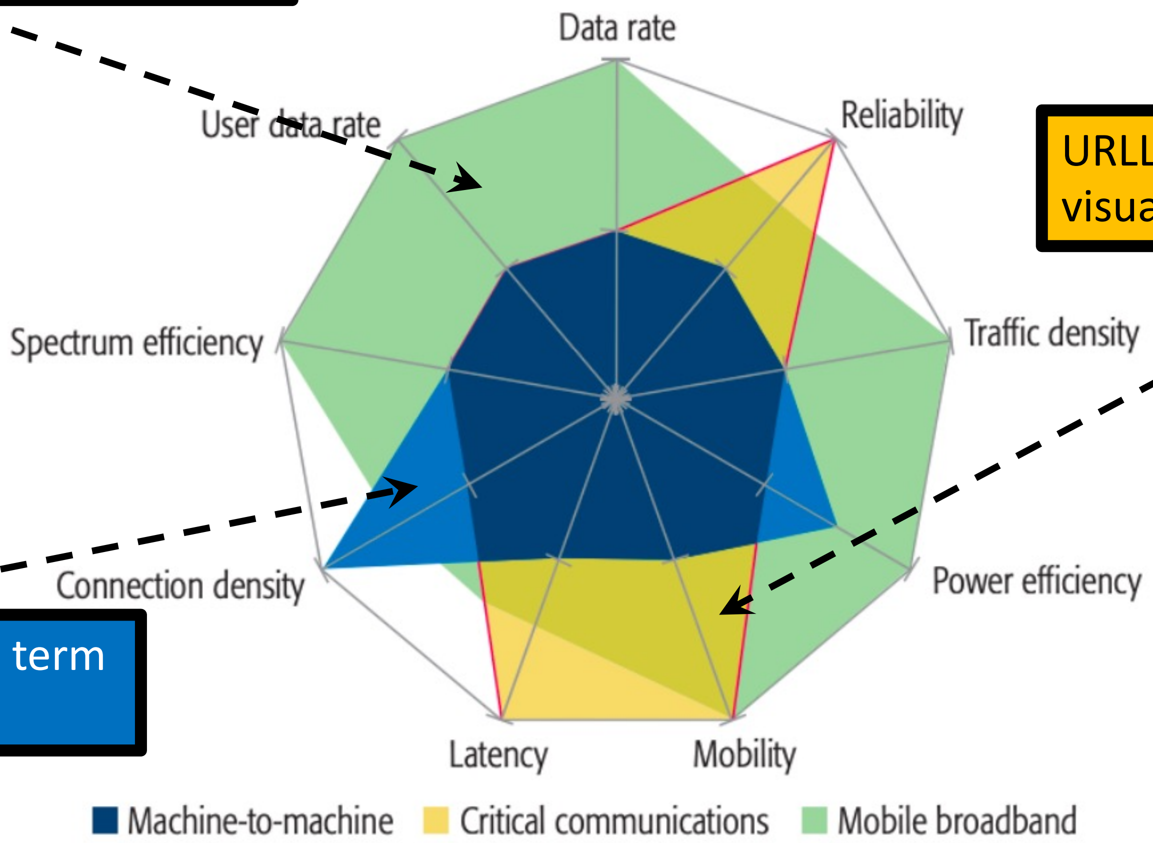
Guan et al, «A Service-Oriented Deployment Policy of End-to-End Network Slicing Based on Complex Network Theory», April 2018

5G Network Slicing: A Slice for UAVs?

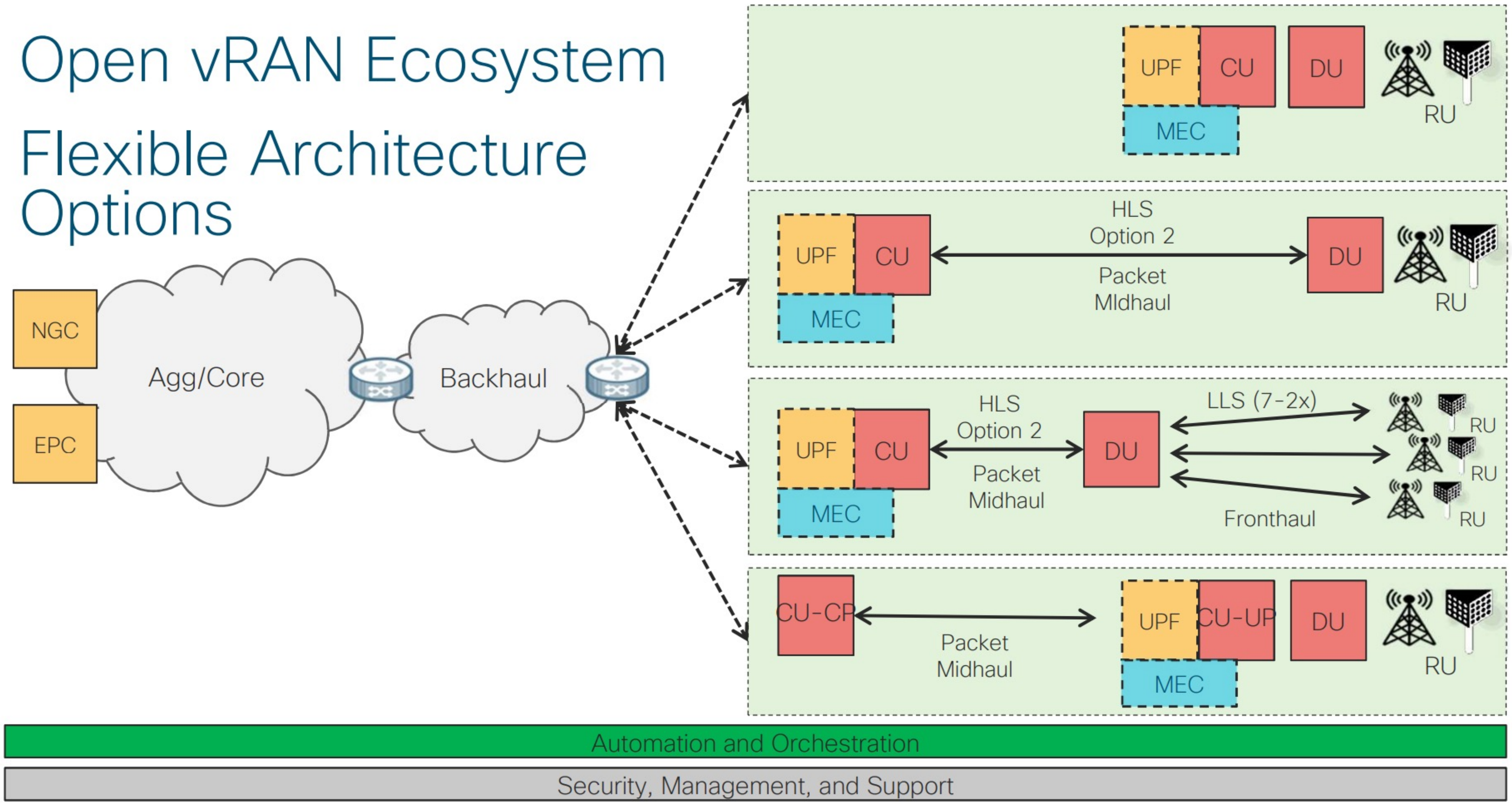
eMBB for HD streaming from UAVs

URLLC for controlling UAVs beyond visual line of sight (BVLoS)

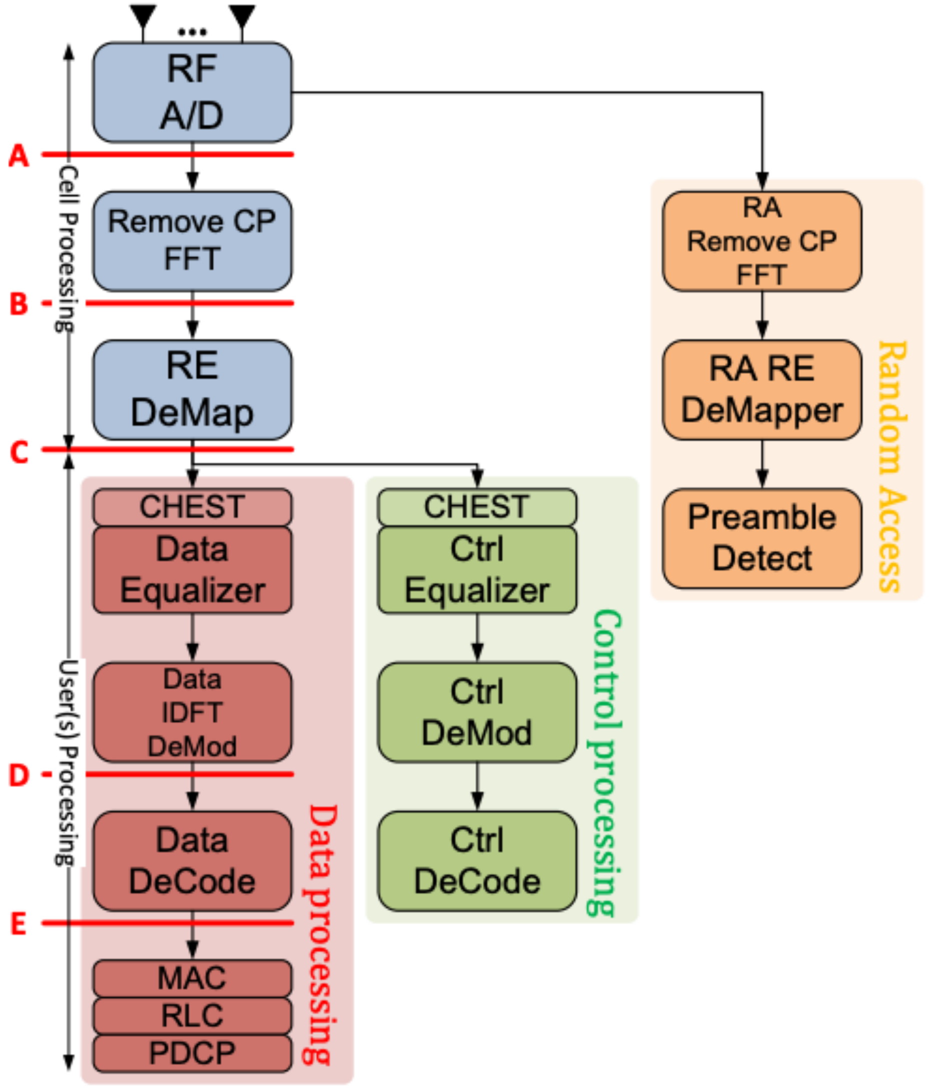
mMTC for small payload, long term connections (UTM)

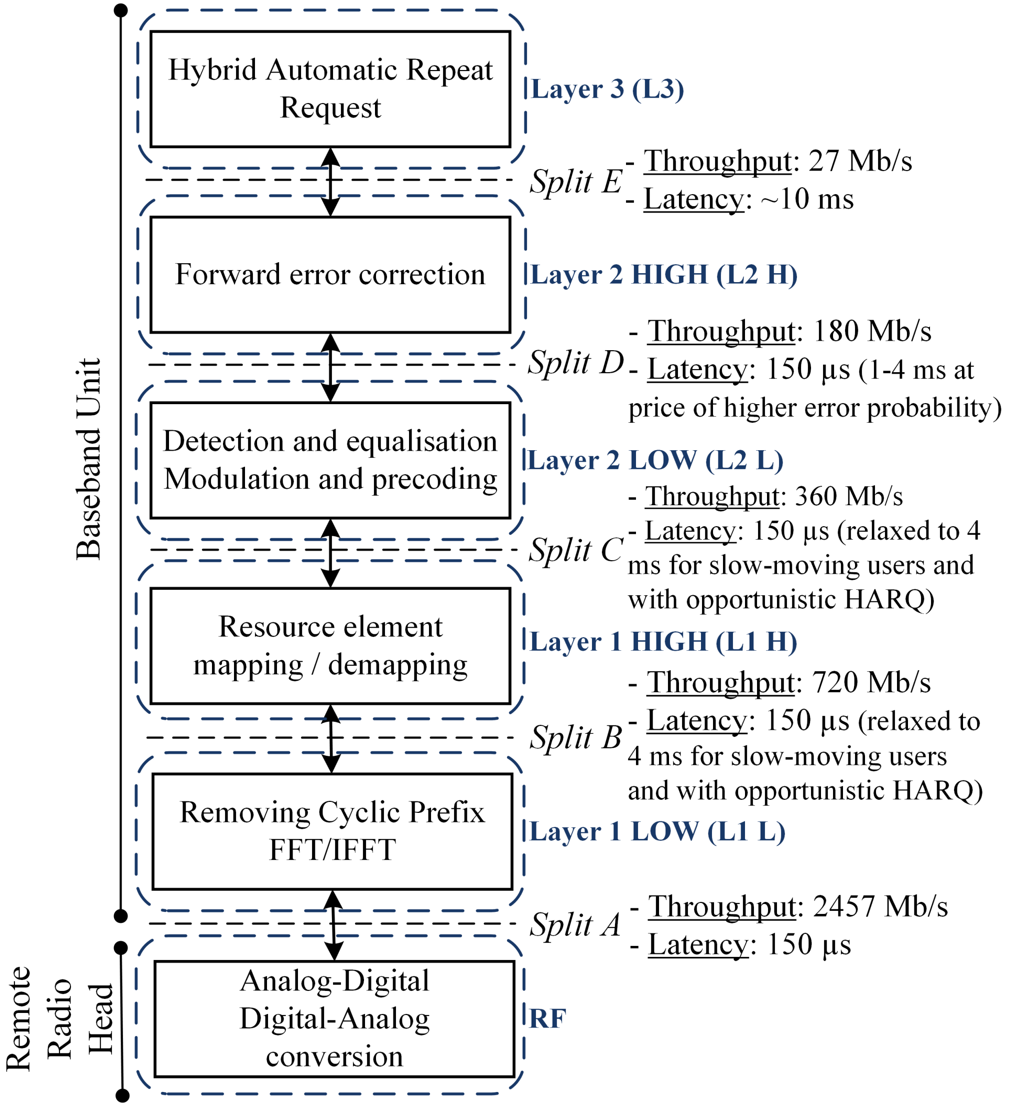


Exploiting the concept of Open vRAN



RRH/BBU Split: Requirements

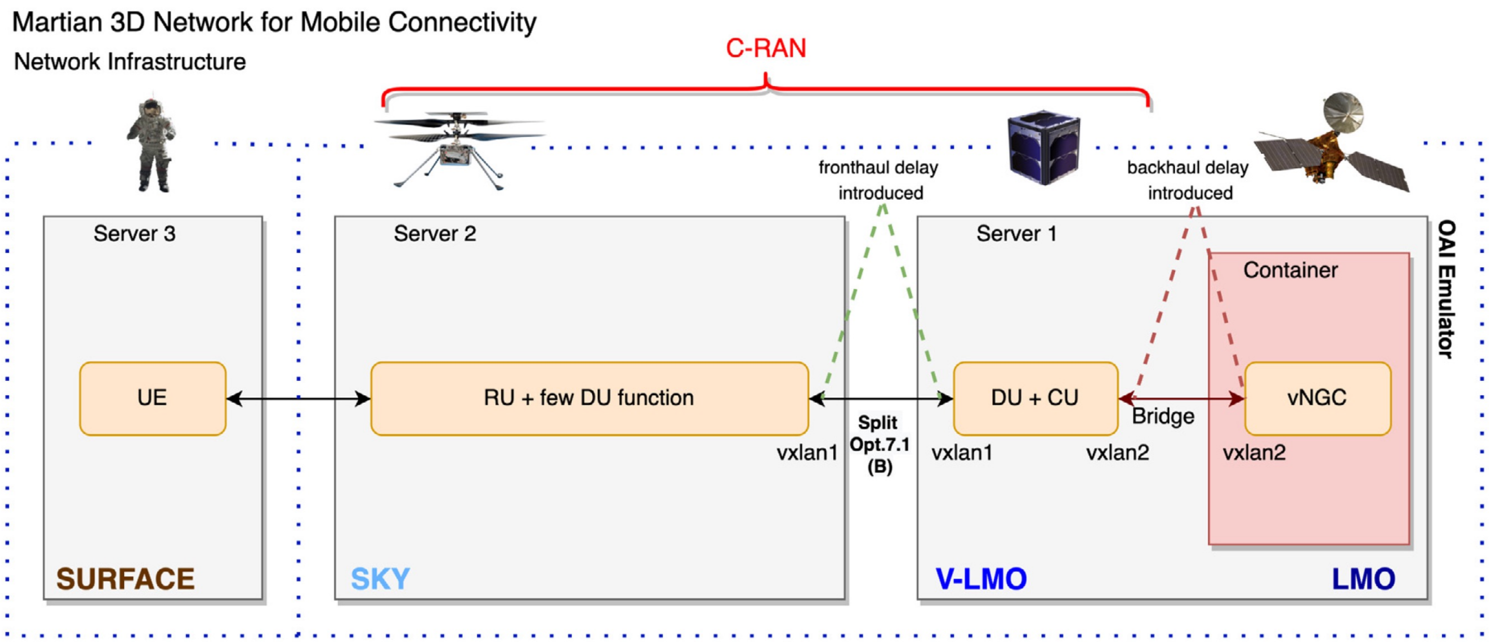


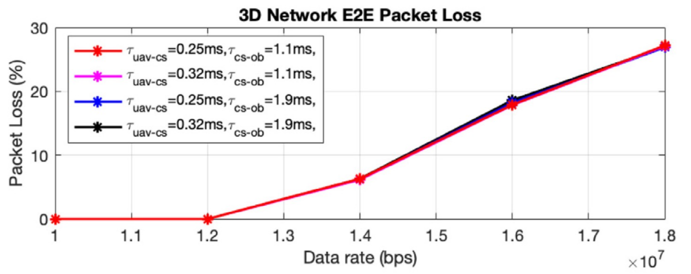


Connectivity with UAVs + satellites

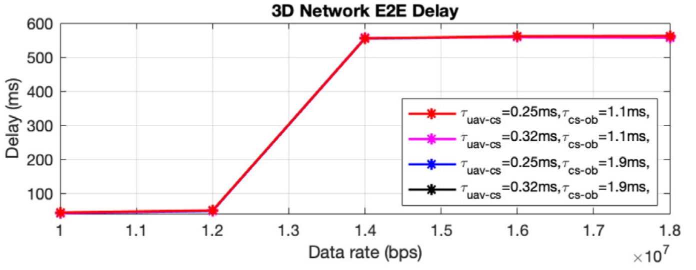
- End-to-end network emulation results

Martian 3D mobile network based on function splitting and virtualization emulated with OAI

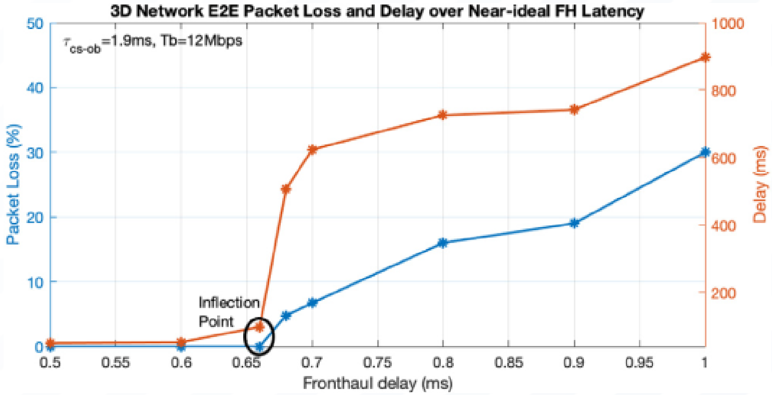




(a) E2E Packet Loss



(b) E2E Delay



[10] S. Bonafini, C. Sacchi, R. Bassoli, K. Kondepu, F. Granelli, F. H.P. Fitzek, «End-to-end performance assessment of a 3D network for 6G connectivity on Mars surface», **Computer Networks**, Volume 213, 2022, 109079, https://doi.org/10.1016/j.comnet.2022.109079.

Open UAVs communication challenges

- UAV networking performance constraints and performance modeling
- Emergency / Public Safety communications
- UAV Traffic Management
- V2V and V2I Communications
- Integration in 5G/6G as aerial BSs and edge nodes
- AI/ML/Analytics (Digital Twin)
- From human control to automation

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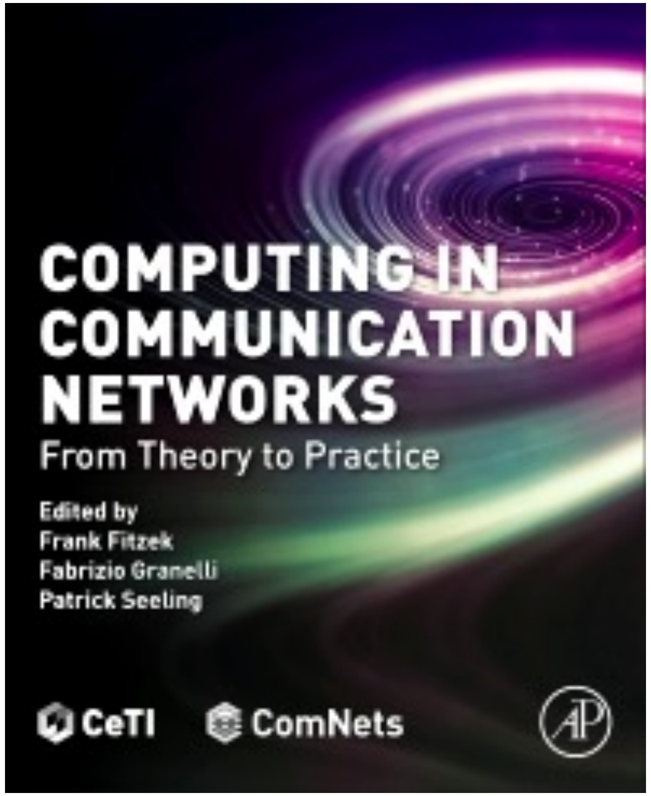
Any questions?



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