Requirements for an Integrated UAS CNS Architecture

2017 Integrated Communications Navigation and Surveillance (ICNS) Conference, April 18-20, 2017 (paper number 180)

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NASA Contract NNA16BD84C

- **NASA Safe Autonomous Systems Operation (SASO) – Communications, Networks and Surveillance (CNS)**
- **Reliable and Secure CNS and Networks (RSCAN) project**
- **18 month performance period**
  - Contract signed August 17, 2016
  - Kickoff meeting (work begins) September 17, 2016
  - **UAS CNS Requirements Report submitted December 17, 2016**
  - **First midterm review February 17, 2017**
  - Final deliverable February 17, 2018

UAS CNS Requirements Report

- UAS operations considered in class A, B, C, D, E, G airspace and unregulated airspace between 200-400’
- Cites FAA Part 107 of Title 14 Code of Federal Regulations (“Part 107”)
  - FAA regulations for small UAS (sUAS) under 55lbs
  - UAS example use cases given
- Considers scaling to accommodate large-scale UAS populations
  - Comms scaling (wireless RF capacity; Internet Protocol scaling)
  - Navigation and surveillance in crowded skies
  - alignment with NASA Unmanned Air Traffic Management (UTM) vision
- Considers existing and emerging datllink technologies, including SATCOM, L-Band, C-Band, AeroMACS, 4G, WiFi and Bluetooth
- Integrated Position, Navigation & Timing (PNT) considered with optimized C-SWAP+P (Cost – Size, Weight and Power + Performance)
- Requirements for improved UAS surveillance systems for UAS missions in controlled and uncontrolled air spaces

UAS Use Cases

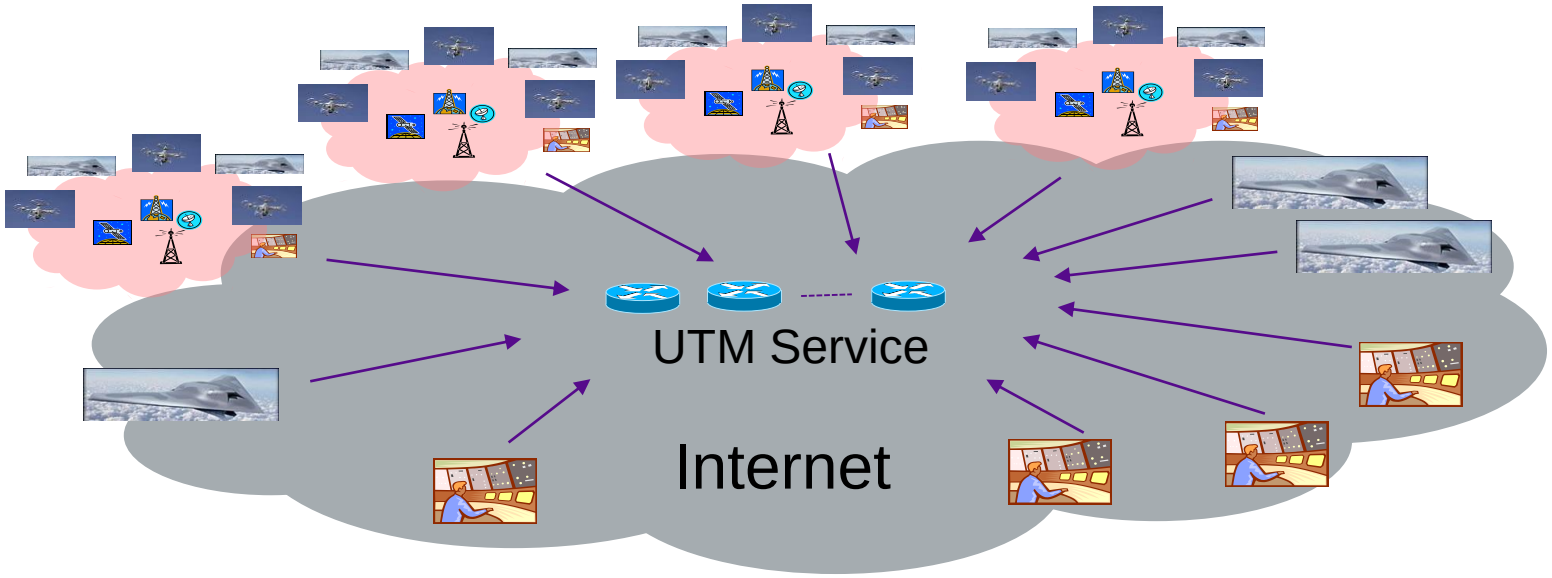
- Agriculture
- Forest fire monitoring and control
- Search and Rescue
- Disaster relief
- Infrastructure monitoring (e.g., railways, powerlines, etc.)
- High altitude, long endurance surveillance
- Unmanned freighter
- Border and coastal patrol
- Law enforcement support
- News gathering
- Parcel deliveries
- Personal use (e.g., aerial photography, hobbyists, etc.)
- Many others

UAS Communication Network CONOPS

- **Unmanned Air Traffic Management (UTM) network needed for harmonized UAS Air Traffic Control (ATC)**
- **Near-term UAS missions will be driven by ground pilots for tactical control with UTM ATC for strategic advisory oversight**
- **Longer-term will see more and more autonomy in UAS**
  - **No ground pilot, or ground pilot as passive monitor**
  - **UTM ATC must be able to take control at any moment**
- **UTM will connect all categories of UAS (small to large) throughout all phases of flight**
- **Requirements Report addresses Communication Network Requirements**

The Unmanned Air Traffic Management (UTM) Global Network

- Overlay layered on top of the global public Internet
- Securely interconnects UAS enclaves with nationwide/worldwide coverage
- **IPv6 addressing** for reaching each enclave
- Larger UAS show up as **mobile IPv6 subnets**
- UTM ATC has full global world view
- Must scale to millions of IPv6 subnets and end systems



UAS Communication Network Requirements

- **REQ CN1: UTM Global Internetwork Service**
  - Overlay network using dedicated links and/or encapsulation
  - Based on IPv6; uses existing Internet links such as 4G/5G
- **REQ CN2: Global Addressing**
  - UTM end systems require a global IPv6 address or subnet
- **REQ CN3: Multilink Support**
  - Must support use of multiple data links that may have limitations such as range, bandwidth, latency, etc.
  - Maintain a stable and unchanging IPv6 address
- **REQ CN4: Scalability**
  - Need a scalable addressing architecture (IPv6)
  - Need to accommodate millions of UAS
- **REQ CN5: Global Mobility Support**
  - Maintain persistent IPv6 addresses across mobility events

UAS Communication Network Requirements

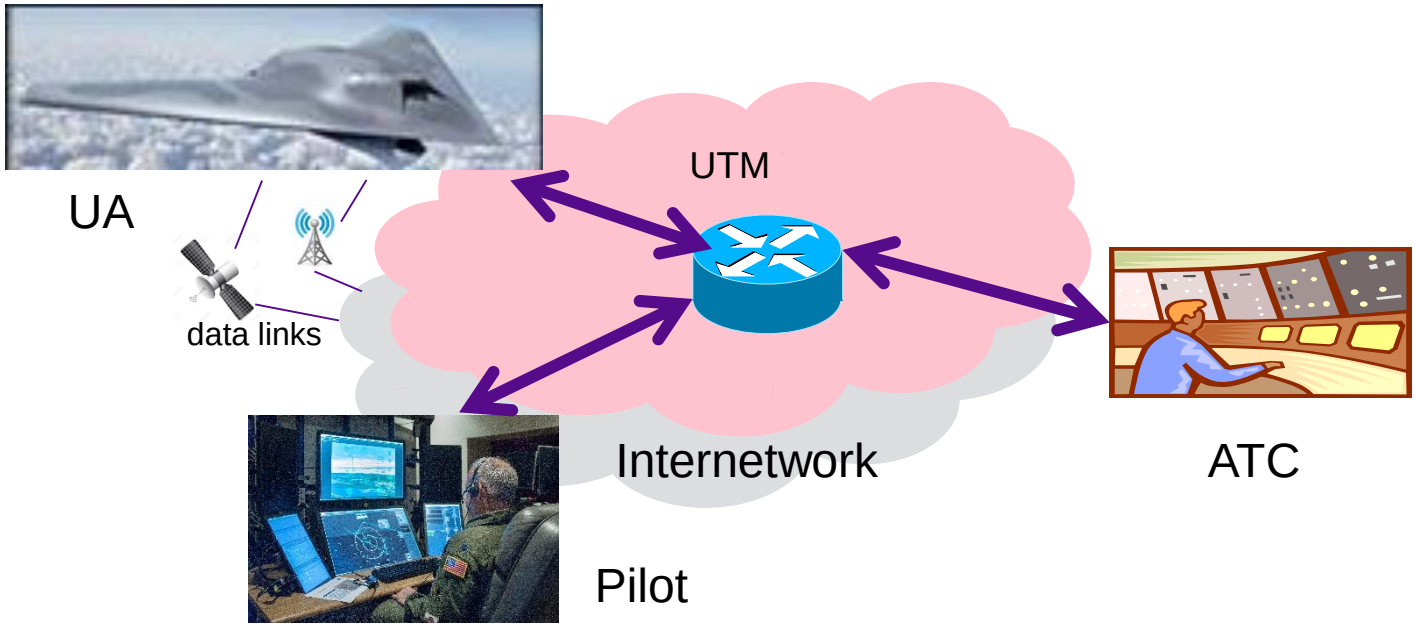
- **REQ CN6: Small UAS (sUAS) in uncontrolled airspace**
  - Soon be millions of sUAS registered in the US
  - Need to support comms for both ground pilots and UTM ATC
- **REQ CN7: Large UAS in controlled air space**
  - Under control of ground pilots who coordinate with UTM ATC
  - Ground pilot role becomes advisory with higher levels autonomy
- **REQ CN8: Reliability and Fault Tolerance**
  - Need a “better-than-best-effort” service in the network
  - Reliable network protocols such as BGP
  - Reliable UAS multi-link management

UAS Communication Network Requirements

- **REQ CN9: Security**
  - Secure against Distributed Denial of Service (DDoS) attacks
  - Protect Confidentiality, Integrity and Authentication
  - Link-layer encryption, Mobile VPNs, End-to-End Security
- **REQ CN10: Command and Control (C2) Messaging**
  - Pilot-to-UAS tactical messaging via STANAG 4586
  - ATC-to-pilot strategic messaging via CPDLC
- **REQ CN11: Situation Awareness (SA) Messaging**
  - Need to accommodate streaming media such as motion video
  - In addition to C2 messaging; possibly using same data links
- **REQ CN12: Communications in Off-Nominal Conditions**
  - Need “lost link” procedures
  - Delay/Disruption Tolerant Networking (DTN)

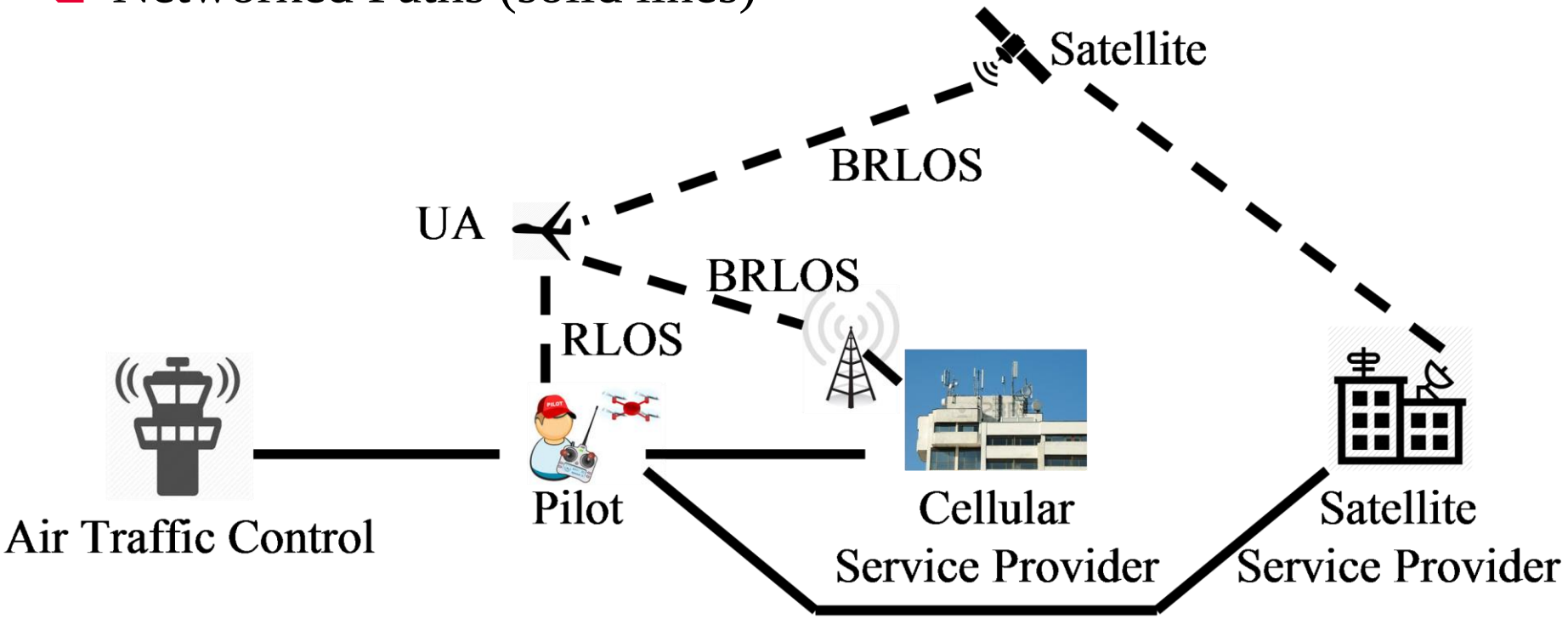
Communication Network Overlay

- **UAS operating in UTM IPv6 routing system**
- **UAS connects to Internetwork via any available data links**
- **Pilot and ATC may or may not be co-located with data link ground support infrastructure**
- **IPv6 routing in the UTM overlay joins all correspondents**



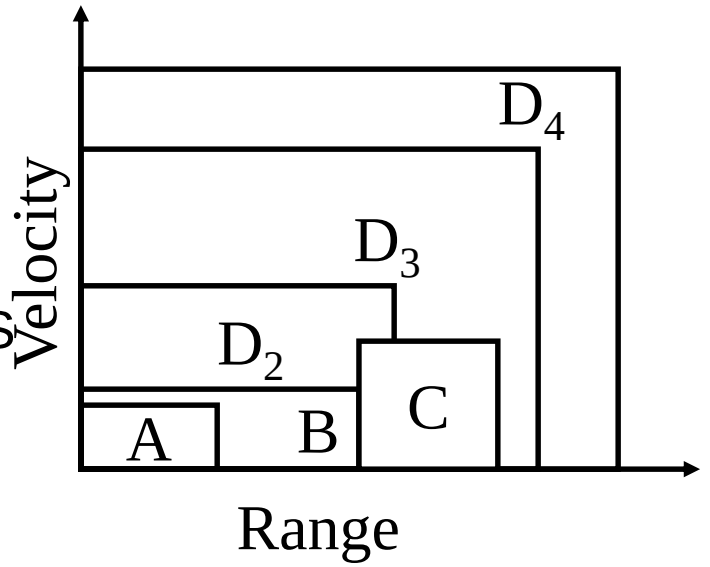
Communications Data Link CONOPS

- Single Control: ATC control via pilot; pilot to UAS
- Control and Non-Payload Communication (CNPC)
- Direct Links (dashed lines)
- Networked Paths (solid lines)



Proposed Mission Categories

- **Category A**:
  - For recreation or sport
  - Unregulated but guided
  - VLOS, 200 AGL, Low Velocity
- **Category B**:
  - Commercial/Governmental, VLOS
  - Regulated, non-airport, 400 AGL, Low Velocity
- **Category C**:
  - Beyond VLOS
  - Larger than category B $\Rightarrow$ Kinetic energy
  - Non-airport, 400 AGL, Higher velocity
- **Category D**:
  - Similar to manned aircrafts
  - Access to NAS including civilian airports, >700 AGL
    1. On-Ground
    2. Taxi and Take-off
    3. En-Route
    4. Oceanic



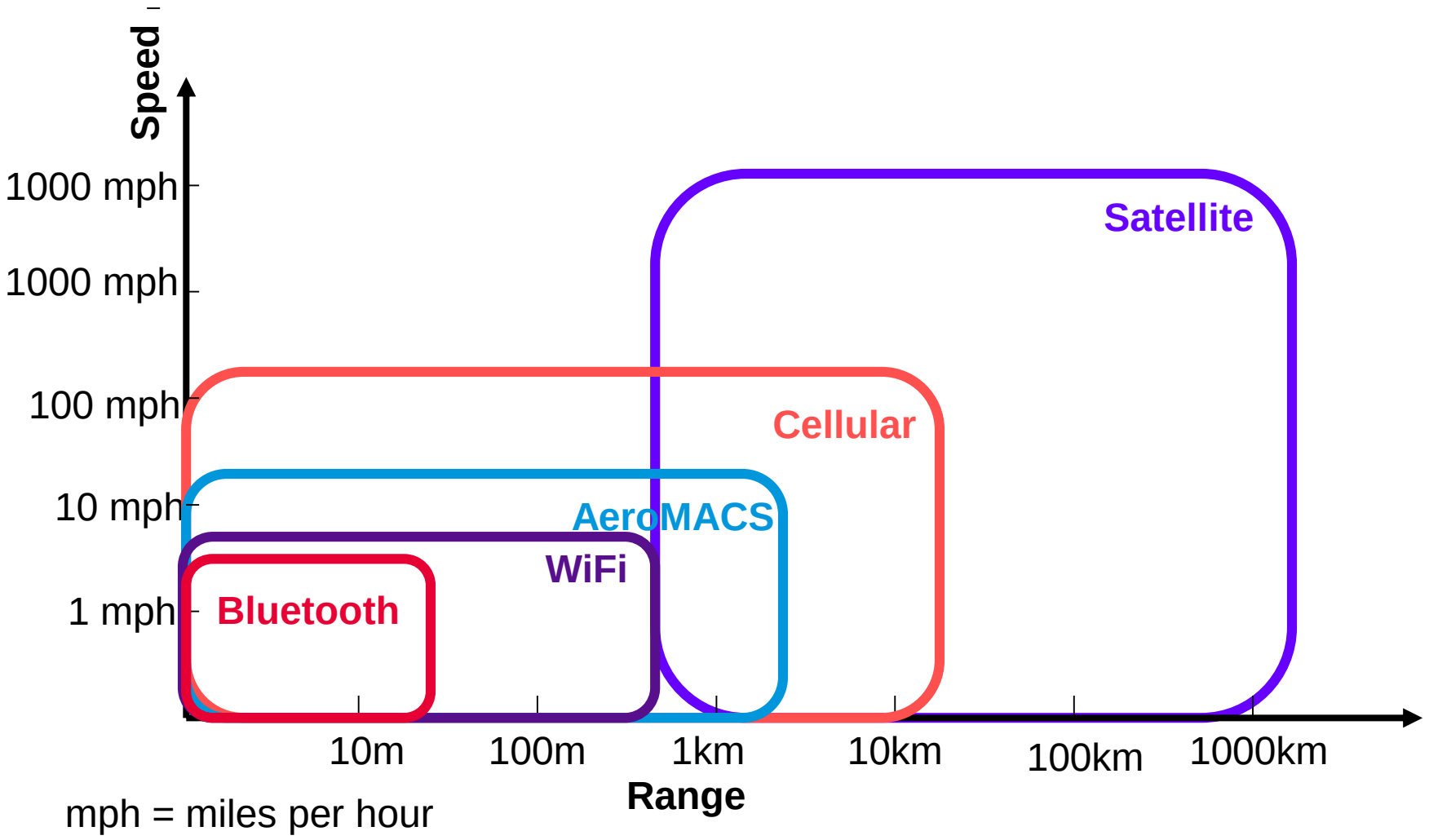
UAS Communication Data Link Requirements

- **REQ DL1: Range**
  - Transmission distance of the last hop of the network to the UAS
  - Mission Category A/B/C/D have different range requirements
- **REQ DL2: Velocity**
  - Speed of UAS affects the choice of data link technology
  - 100km/hr for Category A/B/C
  - Up to 2000km/hr for Category D
- **REQ DL3: Latency**
  - Affects how far UAS can deviate from its trajectory
- **REQ DL4: Availability**
  - Category A/B require 99.99%
  - Category C/D require 99.999%

UAS Communication Data Link Requirements

- **REQ DL5: Integrity**
  - Refers to bit error rate (BER)
  - Recovered by various error correction schemes
  - Detected BER should be less than 10^{-3}
  - Undetected BER should be less than 10^{-6}
- **REQ DL6: Security**
  - All UAS data links required to be at least as secure as WPA2
- **REQ DL7: Bit Rate**
  - Depends on level of autonomy
  - Fully autonomous UAS requires lower data rates

Suitability of Various Datalinks

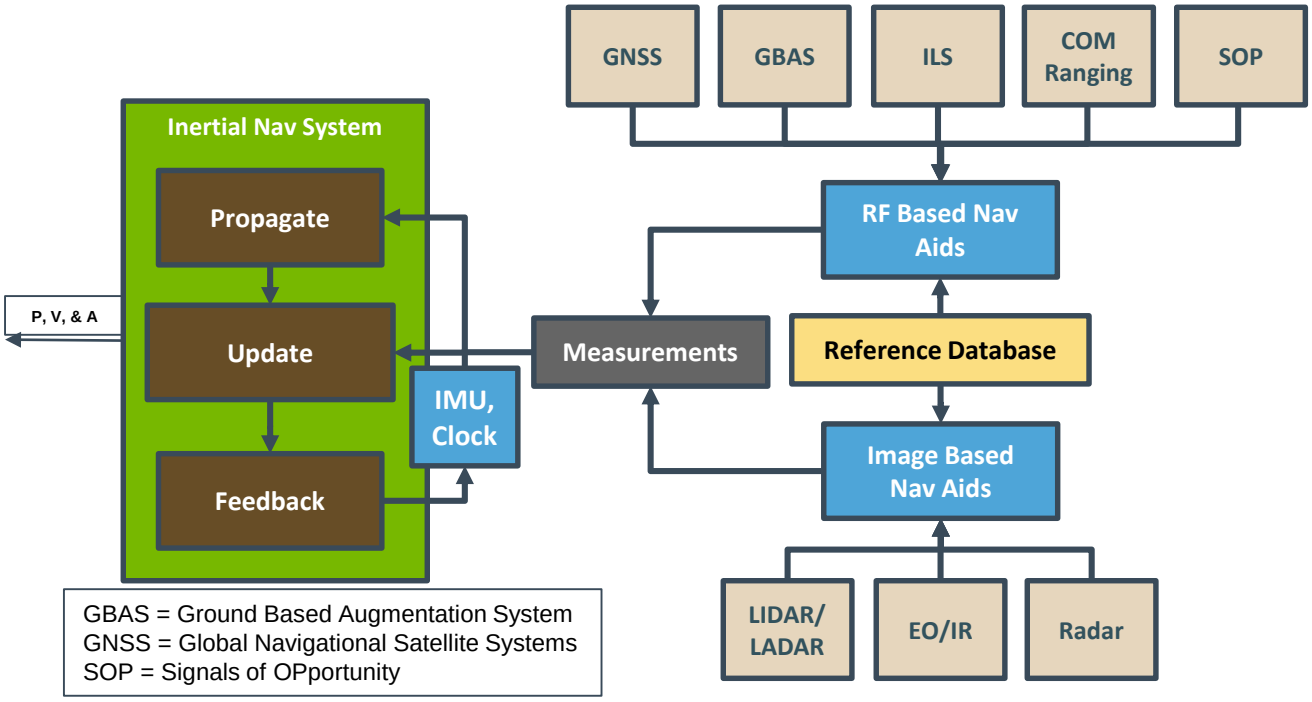


mph = miles per hour

UAS Navigation CONOPS

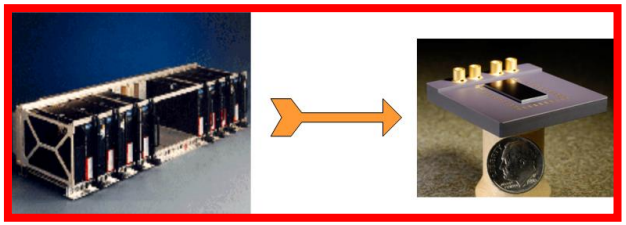
- **Augment GPS and GPS sourced navigation aids using multi-sources/sensors**
- **Define/develop certifiable UAS Navigation Computer for use on all UAS operating in all classes of airspace**
- **Define/develop UAS Navigation Aiding error and correction techniques/solutions**
- **Define level of navigation accuracy needed for bounded range of maneuverability of various classes of UASs**
- **Define UTM/ATM UAS Navigation Message Schema**
- **Define navigation accuracy to support BLOS closed loop operations in NAS**
- **Define navigation accuracy needed to augment human in/on the loop during period of autonomous operations**

UAS On-board Navigation Architectural Framework



- Support launch to recovery in all airspace classes
- Global Navigation Accuracy: GPS equivalent
- All-Weather; 24/7 Availability
- Operating Altitude: Sea Level to 65K feet
- Augment human in/on the loop with better than GPS-like position & velocity accuracy
- Improved C-SWaP+P (cost, size, weight, & power + performance) through the use of integrated modular avionics and software virtual machine computing

A flexible resilient position, navigation, and timing system.



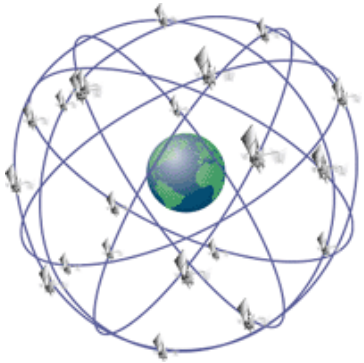
UAS Navigation Requirements

- **REQ NV1: GPS Augmentation**
  - Operate in GPS-denied conditions
  - Vision/image-based; Signals of Opportunity; etc.
- **REQ NV2: Certifiable Navigation Computing Architecture**
  - Safety certification needed for safe integration of UAS
  - Need cost-affordable certifiable computing architecture
- **REQ NV3: Navigation Source Error Detection and Correction**
  - Interference, jamming, spoofing need to be detected
  - Compare RF-based; non-RF-based nav source calculations
- **REQ NV4: Ground Controlled UAS Navigation Accuracy**
  - Define UAS maneuverability profile
  - Define worst-case closed-loop time

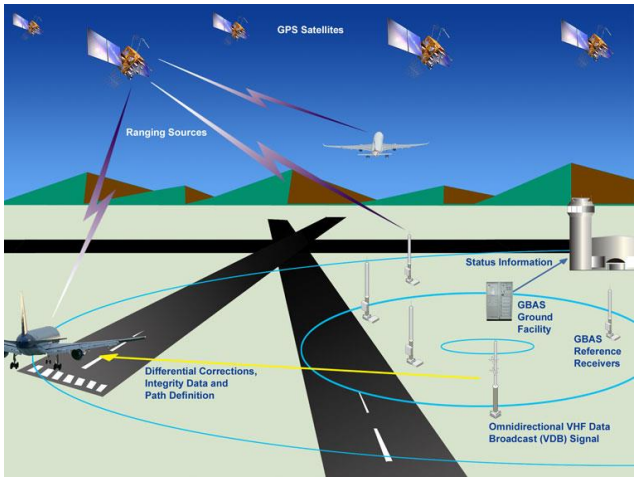
UAS Navigation Requirements

- **REQ NV5: Universal Navigation Message Schema**
  - STANAG 4586 messaging schema assumed
  - Define STANAG 4586 extensions for navigation information
- **REQ NV6: BLOS Navigation Accuracy**
  - Satellite communication delay is a problem
  - High availability navigation needed for autonomous operations
- **REQ NV7: Autonomous Navigation Accuracy**
  - Need advanced sensor capabilities for precision applications such as autonomously landing a UAS on a stationary pad

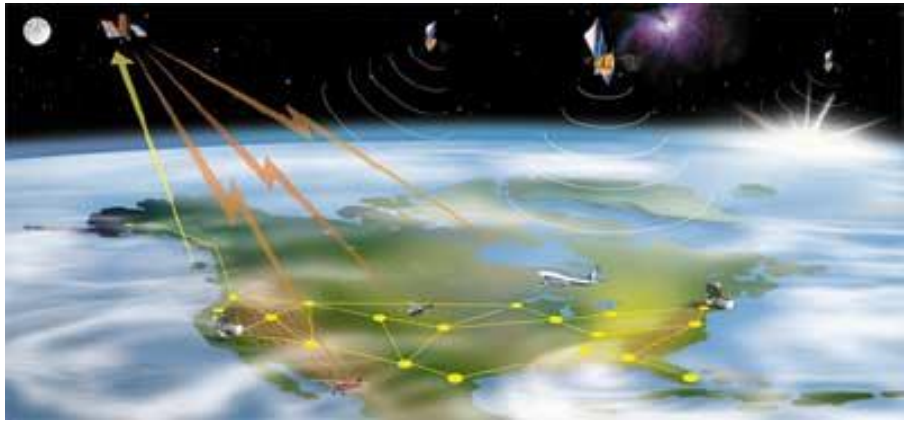
RF Based Navigation Aids



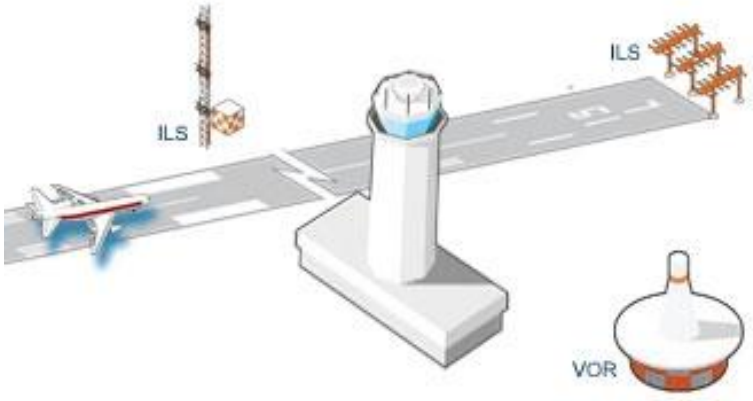
GPS



Ground Based Augmentation System (GBAS)



Wide Area Augmentation System (WAAS)

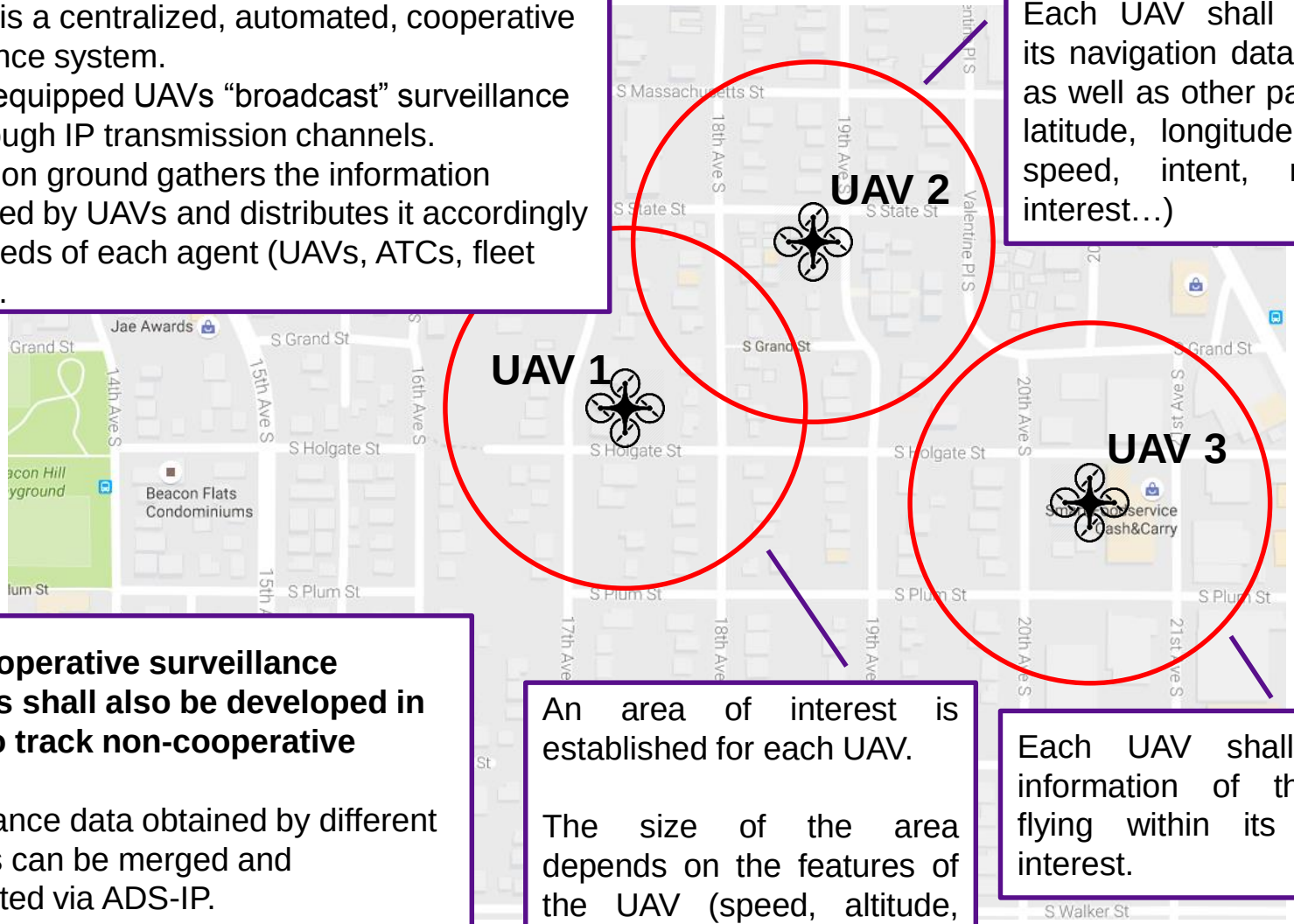


Ground-Based Navaids (GBN)

UAS Surveillance CONOPS

ADS-IP

- ADS- IP is a centralized, automated, cooperative surveillance system.
- ADS-IP equipped UAVs “broadcast” surveillance data through IP transmission channels.
- A server on ground gathers the information transmitted by UAVs and distributes it accordingly to the needs of each agent (UAVs, ATCs, fleet owner...).



Each UAV shall announce its navigation data (position, as well as other parameters: latitude, longitude, altitude, speed, intent, range of interest…)

- **Non-cooperative surveillance systems shall also be developed in order to track non-cooperative targets.**
- Surveillance data obtained by different systems can be merged and transmitted via ADS-IP.

An area of interest is established for each UAV.

The size of the area depends on the features of the UAV (speed, altitude, mission, etc.).

Each UAV shall receive information of the UAVs flying within its area of interest.

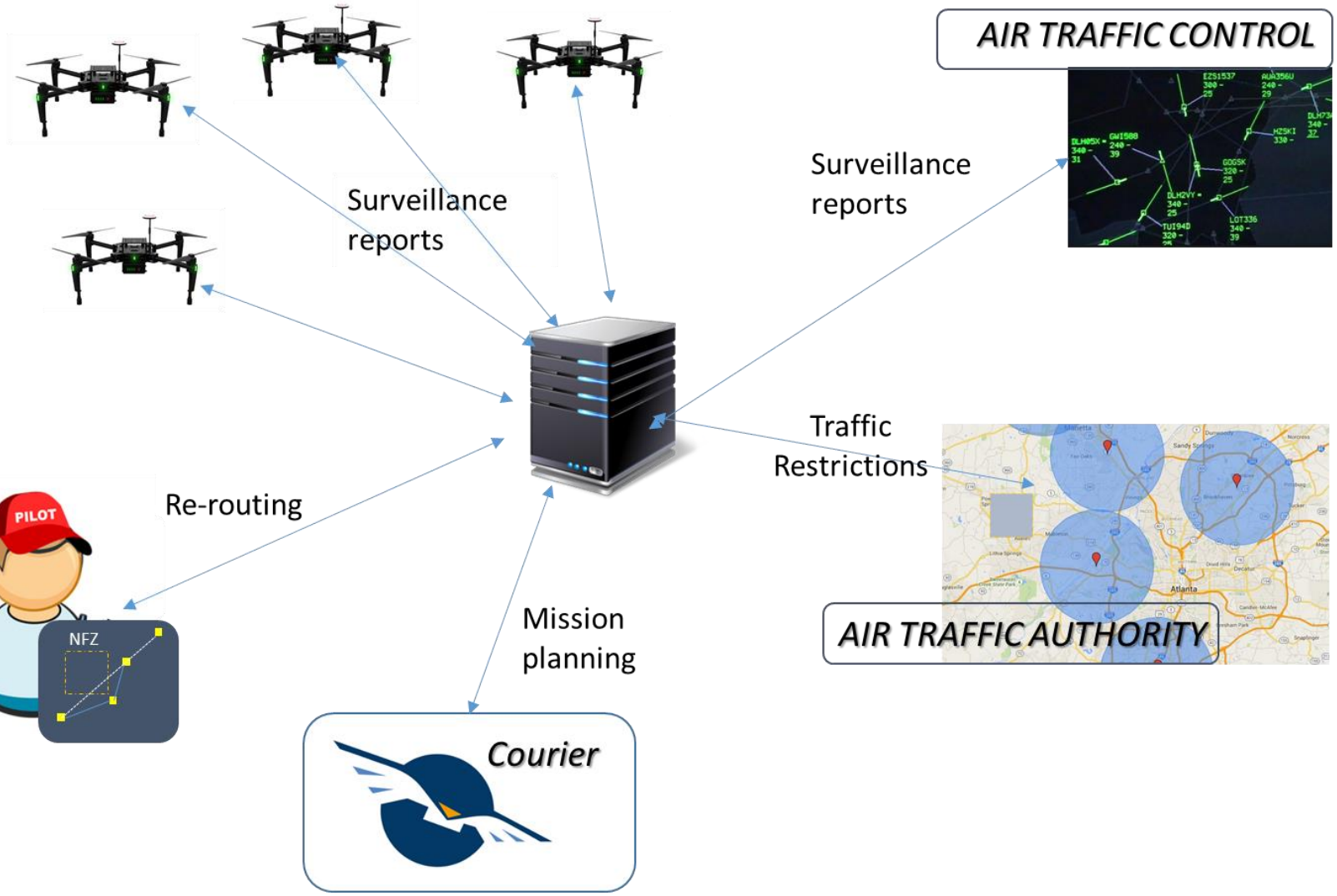
UAS Surveillance Requirements

- **REQ SV1: Safety**
  - Allow UAS to operate without increasing risk
  - Surveillance system must maintain or increase safety cirteria
- **REQ SV2: Capacity**
  - SSR; ADS-B 1090Mhz data link close to saturation
  - Need alternative data links and networks
- **REQ SV3: Efficiency**
  - Need efficient systems to accommodate increasing air traffic density and complexity
- **REQ SV4: Security**
  - Legacy surveillance systems not secure
  - Security needed to defeat spoofing, jamming, cyber attacks

UAS Surveillance Requirements

- **REQ SV5: Integration**
  - Integration into controlled and uncontrolled air space
- **REQ SV6: Dependent Cooperative Surveillance**
  - Include ADS-B benefits while overcoming its vulnerabilities
- **REQ SV7: Non-Cooperative Surveillance**
  - New technologies needed (image recognition, noise/RF signature detection, etc.)
- **REQ SV8: Surveillance Data Flows**
  - Data interchanges needed between UAS, commercial aircraft, ATCs, AOCs, etc.)
- **REQ SV9: Performance**
  - Need continuously updated presentation of surveillance info

IP-based surveillance system for UAS



Backups