National Aeronautics and Space Administration

C2-Communications Concept Architecture Presentation

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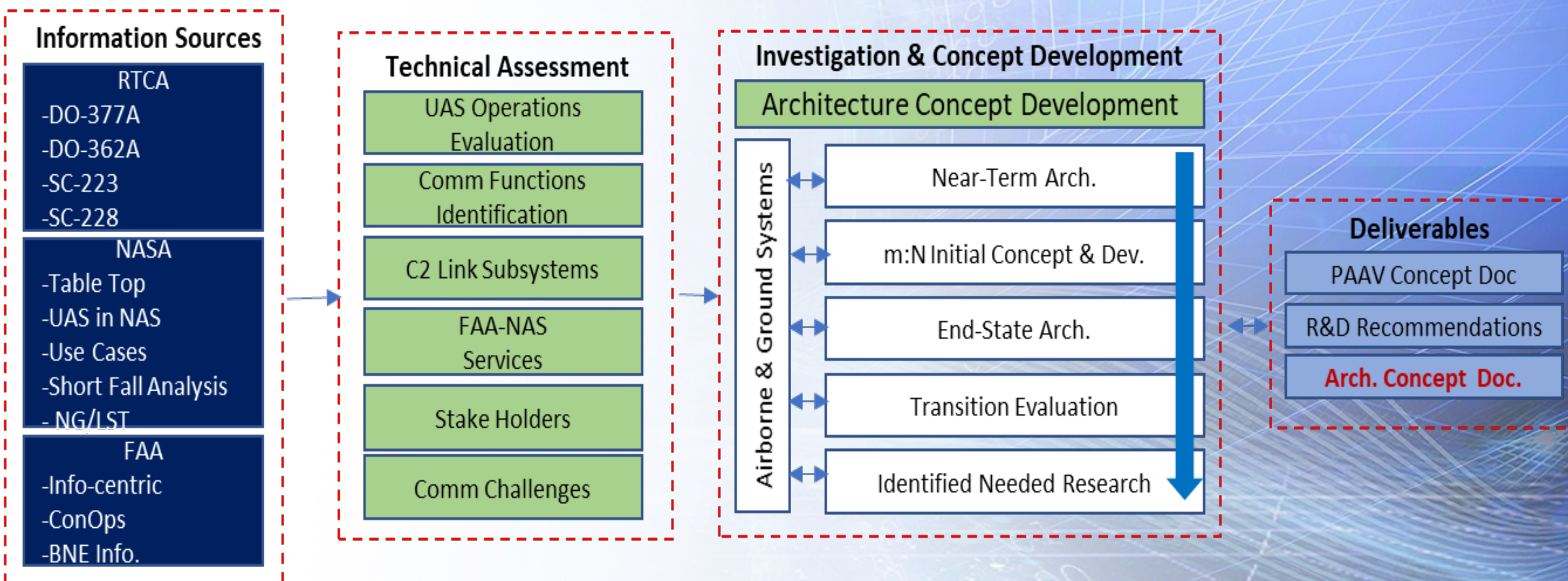
Presentation Outline

1. Introduction
2. Document Objectives and Concept development assumptions
3. UAS C2-Communication Operations, Functions and Challenges
4. C2 Link Technologies overview
5. New Function introduction
6. C2-Communications Architecture Concept Description
7. UAS Communications Architecture Subsystems
8. Summary and Questions

Introduction

Architecture Development Workflow



Objectives and Assumptions

Objectives

- Define a conceptual C2-Communications functional architecture.
- Define a concept for evolution to an advanced long-term architecture solution.
- Identify gaps or shortfalls in current and long-term technologies.
- Identify research areas for new technology and components that improve overall performance or enable new operations.
- Architecture will follow these principles: Scalability, Resilience, Security, and Evolvability

C2-Communication Concept Development Assumptions

- UAS for Air-cargo (and other UA services that use same aircraft type) will be required to use standards compliant C2 link systems.
- Standardized UAS C2 Link systems will be available.
- The UAS C2-Communications architecture provides connectivity for UA C2 operations.
- The UAS C2-Communications architecture provides connectivity for dialog, information, and data flow between operators and UAS/FAA management and air navigation services.
- UAS C2-Communication systems will be authorized to interface with NAS/FAA systems and infrastructure.
- The UAS C2-Communications architecture will follow an evolutionary development and implementation approach.
- The aviation community will move towards a zero trust cyber-security strategy and C2-Comm architecture must be compliant.

C2-Communications Architecture Concept Considerations

What was considered in deriving the concept architecture:

- UAS Operations (Doc Section 3)
- UAS C2-Communications Functions (Doc Section 4)
- UAS C2-Communications Architecture Challenges (Doc Section 5)

UAS Airspace Operations

- Architecture is required to enable NAS UAS flight operations in all flight stages
- Compiled a tabular listing of general operations with descriptions of C2 and communications activity required (i.e. commands, cmd responses and voice dialog to enable them). Mini use-case narratives.

Surface

Operation	Description
Aircraft Preparation	UA preflight preparation and payload management
Aircraft Systems/Subsystems Configuration	UA Gate Departure flight preparation
Aircraft Checkout	UA Pre-flight subsystems checkout
Flight Planning and Route delineation	UA Flight plan filing
Route/Contingency-route programming	RPIC flight plan coordination with AOC
Surface Taxi	RPIC Taxi operations to departure runway
Surface Taxi contingency operations	Altered Taxi route departure
Takeoff (Class B, C, D Airport)	Runway to Airport Dep Fix or TRACON - Towered
Takeoff (Class E,G - Regional)	Runway to First Sector Contact - Untowered
Post-Arrival Taxiing and Taxi instructions at Arrival airport	Taxi instructions at Arrival airport (Towered or Un-towered)

Airborne

Operation	Description
Departure (Towered Airports)	Transition to ARTCC Airspace
Departure (Un-towered Airport)	Transition to ARTCC Airspace
Enroute	Center-Center and Intra-Center Sector Transitions
Arrival/Landing (Towered Airport)	Transition - Enroute to TRACON or Airport Control
Arrival/Landing (Un-towered Airport)	Transition - Enroute to Regional Airport
ATM/ATC Services	Air Route Traffic Control Center Communications
Enroute Contingency C2 and Communications	Center/Sector operations (Contingency)

General Services

Operation	Description
UAS Regional Management	Operation/state/surveillance data processing and dissemination
UAS Traffic Management	UA Air Traffic route flight coordination
UAS AOC (Fleet Management)	Coordination between RPIC and UAS AOC
UAS Air Cargo Provider Operations	Operations and management of Air Cargo flights

Communications Functionality

- The architecture needs to accommodate a diverse set of communications functions.
- Compiled a tabular listing of primary functions with descriptions that are needed to enable UA operations in the National Airspace
- Included functions in support of advanced operations (e.g. m:N concept)

Primary Functions	Description
C2 Link Availability	Secure C2 link along any UA air-route.
UA Command & Control	RPIC to UA commanding of UA flight systems and all subsystems
UA Telemetry Downlink	Return, distribution, and processing of telemetry data
ATC Voice Comm	Two-way voice communication between ATC and UA remote pilots.
Datalink Communication	RPIC to ATC forward and return of datalink (e.g. CPDLC over VDL2)
C2 Link Management	Management of C2, RF Link, ground radio station to UA connectivity.
UAS Services Comm	Remote Pilots management services (UAS Fleet Ops, UAS AOC, etc.)
FAA/NAS Services Comm	Access to data from SWIM information systems.
Data Sharing	Info-centric data access between FAA/NAS services and UAS Management services.
Advanced Functions	**Description**
Digital ATC Voice Comm	Provision for reduced latency, ground based, digital voice communication
Multi-RPIC UA Control (m:N)	Provision for the ability to transition the remote pilot in command
Multi-UA RPIC Control (m:N)	Provision for RPICs to manage and control multiple UA.

Communications Architecture Challenges

- Unmanned aircraft operations expand the need for communications services in contrast to manned aircraft
- Identified list of the most demanding tasks (as Challenges) that a UAS C2-communication system needs to focus on to provide the unique communications service required for UA operations.

Challenge
Availability of standardized C2 link systems.
Availability of secure networking capabilities to effectively provide RPIC to UA connectivity.
Availability and access to UAS unique (third party?) management and operations services to enable UA flights.
Availability of UAS unique communication technology components to enable UA flights. (e.g. m:N)
Development of standards for automation and/or autonomous systems for UAS ?
Availability of seamlessly integrated systems for data and information distribution between RPICs, NAS/FAA services, and third-party management services for UA operations.
Reduction of RPIC to ATC voice communication latency.
Availability of methods to enable voice communications between RPIC and traffic controllers for corridors operations.
Near-term to End-state technology transition

Approach - Near-term (NT) to End-state (ES) Implementation

Develop an evolutionary concept architecture

Rationale

- Assumed the need for a near-term system for early implementation.
  - Would requires least research or new technology development.
- Near-term architecture would baseline the architecture functionality and provide an initial, operational architecture.
  - NT concept architecture becomes the framework for the system and for upgrade integration.
- Transition to ES architecture with newly developed technologies to allow for more advanced or complicated UA operations.
- In the end the goal was to identify ES architecture evolves as a long-term, target solution for UAS C2-Comm.

Evolution Examples (addressed in our NT to ES approach)

- Evolution of C2 systems technologies (expected as technologies evolve and improve)
- Evolution to ground VoIP for RPIC-ATC Communication
- Evolution from **NT – m≥1:N=1** to **ES - m≥1:N≥1** capability
- In general - evolution and maturity of all functional components (NT to ES)

C2 Link Technologies

Both Near-term and End-state Concept Architectures consider use of three candidate C2 link system types. Terrestrial Cellular, Terrestrial Distributed, and SatCom

- **Terrestrial Cellular (5G-like) System**
  - Pros: Distributed cell sites - inherently would provide continuous connectivity (mobility). Wide bandwidth for C2 with video. Relatively Low latency.
  - Cons: No airborne C2 link system implementation for UAS C2 known to be in development. No Standard for UAS Cellular C2 currently exists.
  - NT Implementation: Currently could accommodate NT time-frame for surface operations (5G systems rollout is occurring now). Could be installed at all Classes of airport.
  - ES Implementation: Service could expand for Airborne operations.
- **Terrestrial Distributed DO-362A System**
  - Pros: Standard is already established. Have seen one vendor with an available radio. Possible follow-on for compatible C-band Satcom standard is in-work. Relatively Low latency.
  - Cons: Limited bandwidth and frequency allocation. Limited video capability. Complex infrastructure. No known roll-out occurring.
  - NT Implementation: Pending system rollout – candidate for Primary system for Airborne operations (wherever ground infrastructure is possible)
  - ES Implementation: Enhanced capabilities and expanded infrastructure could be available. Could be replaced with a cellular system if Airborne Cellular is available.

C2 Link Technologies (Cont.)

- **SatCom System**
  - Pros: Wide coverage area. No ground infrastructure required. LEO systems would provide improved latency over GEO.
  - Cons: Understood to exhibit relatively higher latency – therefore not considered as ideal for heavily congested airspace or takeoff/landing operations. No dedicated UAS system. Would need to schedule and operate through provider services shared by other users.
  - NT Implementation: Use primarily for Enroute (especially over difficult terrain areas where terrestrial systems cannot be deployed). Use as contingency link for locations where terrestrial systems are primary.
  - ES Implementation: Same as NT. Improved performance and dedicated systems developed for UAS would influence expanded usage.

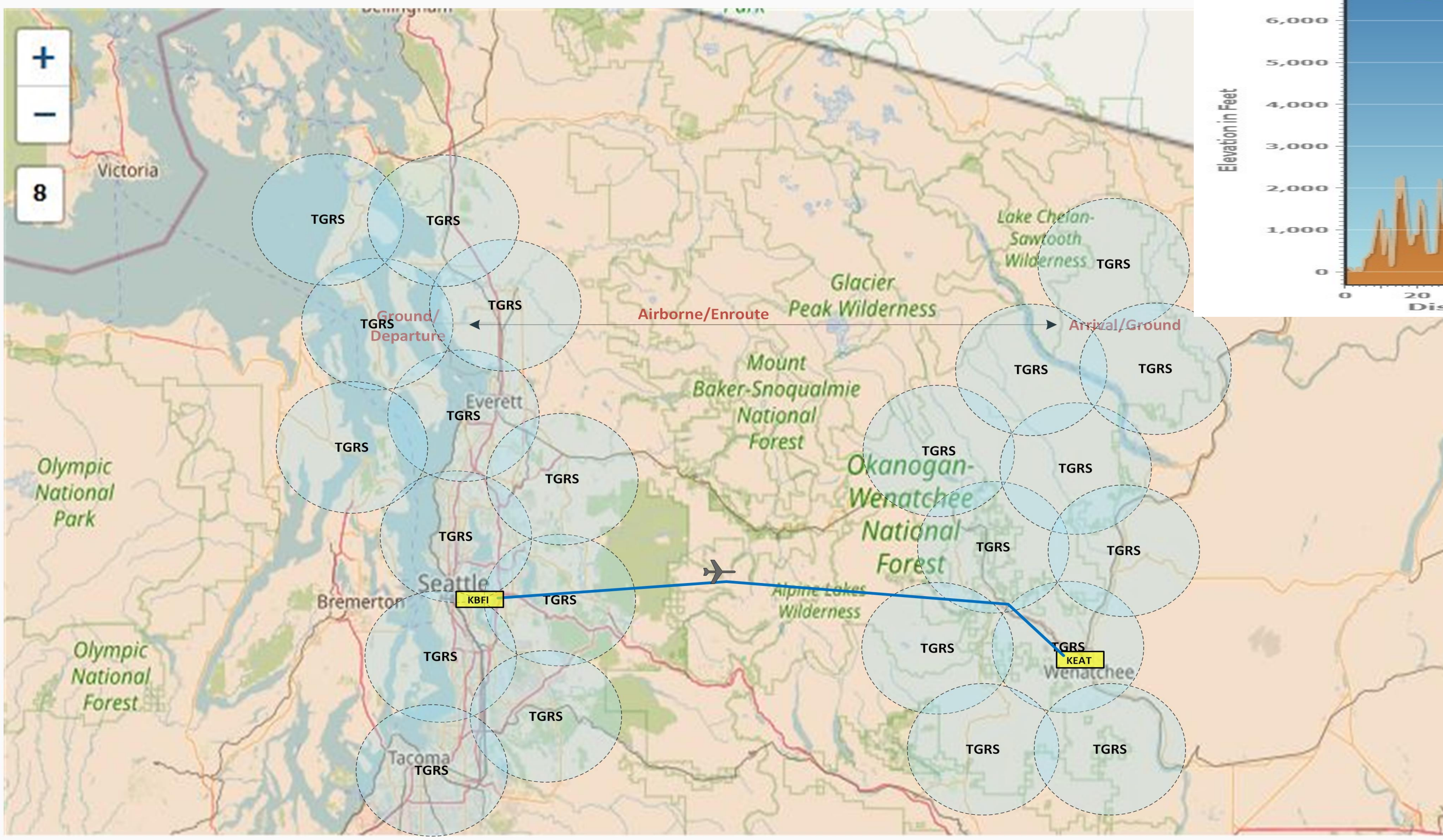
Qualifiers (keeping things in perspective)

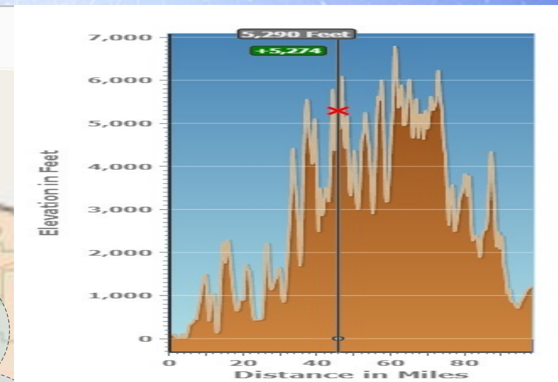
- State of dedicated and standardized UAS C2 Link systems and their development and deployment are TBD.
- Introduction of improved automation or autonomy for UAS will greatly influence C2 link usage.
- From our draft concept document - *Although there are multiple system types as candidate C2 technologies, any broadening of a single technology's ability to provide improved service and performance for operations is encouraged. The primary goal is to provide the best, most reliable, most economical, C2 Link service in all UA/NAS operating areas with an emphasis on safety for all UA flight operations.*

C2 Link Technologies – Interoperability

Use of multiple C2 Link systems requires managed interoperability

UAS Cellular/Terrestrial/SatCom C2 System Concept - Coverage Map Illustration (KBFI – KEAT route)





TGRS = Terrestrial (System) Ground Radio Station ( ) – Cellular Coverage ( ) - C2 Terrestrial GRS Coverage ( ) - C2 SatCom Coverage

C2 Link Technologies – Interoperability (mLMS)

To manage the use and interoperability of multiple C2 Link System Technologies, a link management function is identified for both the NT and ES concept architectures.

Conceptual third-party Service - multiple Link Management Service (mLMS)

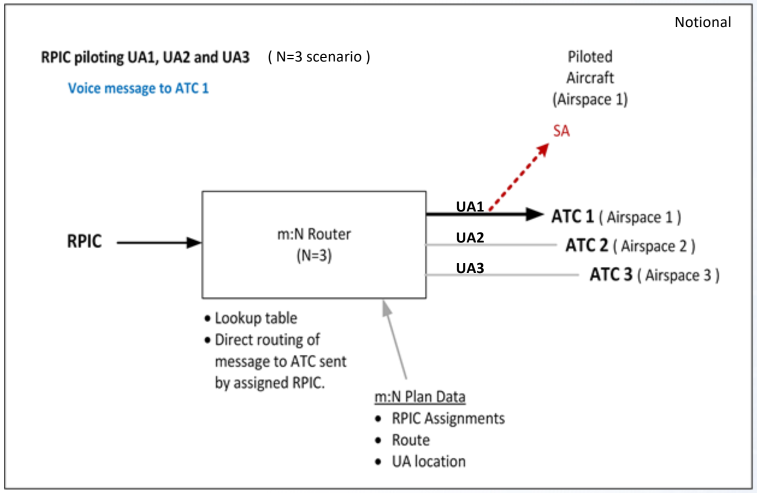
- LMS idea first introduced for DO-362 System for coverage area/frequency planning. DO-362A and DO-377)
  - Expanded in this concept as a per-flight, C2 link management service for planning for system switchovers and terrestrial C2 link system frequency plans.
- Input would be pre-flight, flight plan data and understood C2 System performance and availability along a route.
- mLMS would generate per-UA-Flight, C2 Link connectivity plans.
- mLMS would communicate/distribute a plan for C2 coverage areas to RPICs and ATC (pre-flight).
- mLMS C2 link plans could be automated into a UA flight – with anticipated C2 link changes sent as notifications to RPICs. No active RPIC involvement necessary.
- Service could also assist with C2 link contingency configurations or lost link resolution as needed.

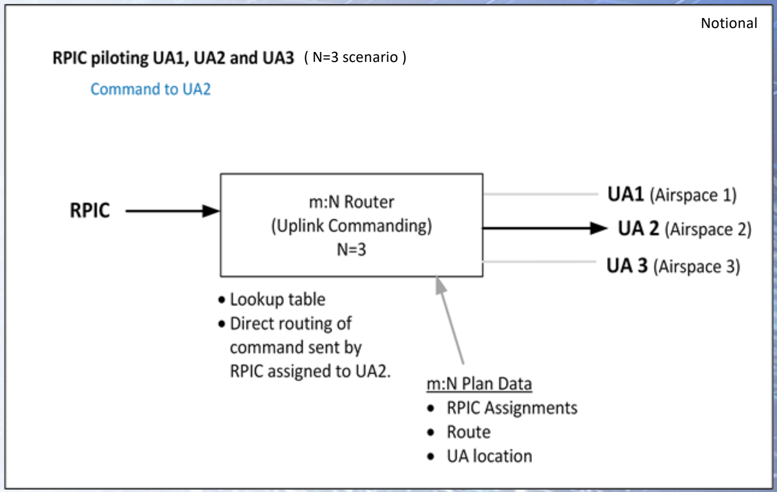
Multi-RPIC per UA, Multi-UA per RPIC (m:N) Control Function

New conceptual routing function identified in the architecture to provide accurate, point-to-point delivery of RPIC-UA-ATC information in m:N scenarios.

Exist in the NT and ES architecture with varied functionality as: m:N Routing components

- Provides for routed delivery of voice messages, C2 Commands, C2 Command responses, VoIP traffic, and datalink messages in m:N operating scenarios.
- Uses flight plan data and planned RPIC-UA assignment data from traffic management resources to populate routing tables for RPIC-UA-ATC associations along a flight route.
- Routers receive regular updates to routing tables from traffic management resources.
- Operate within relevant networks in subsystems to direct data to correct end-user(s) for safety and efficiency.



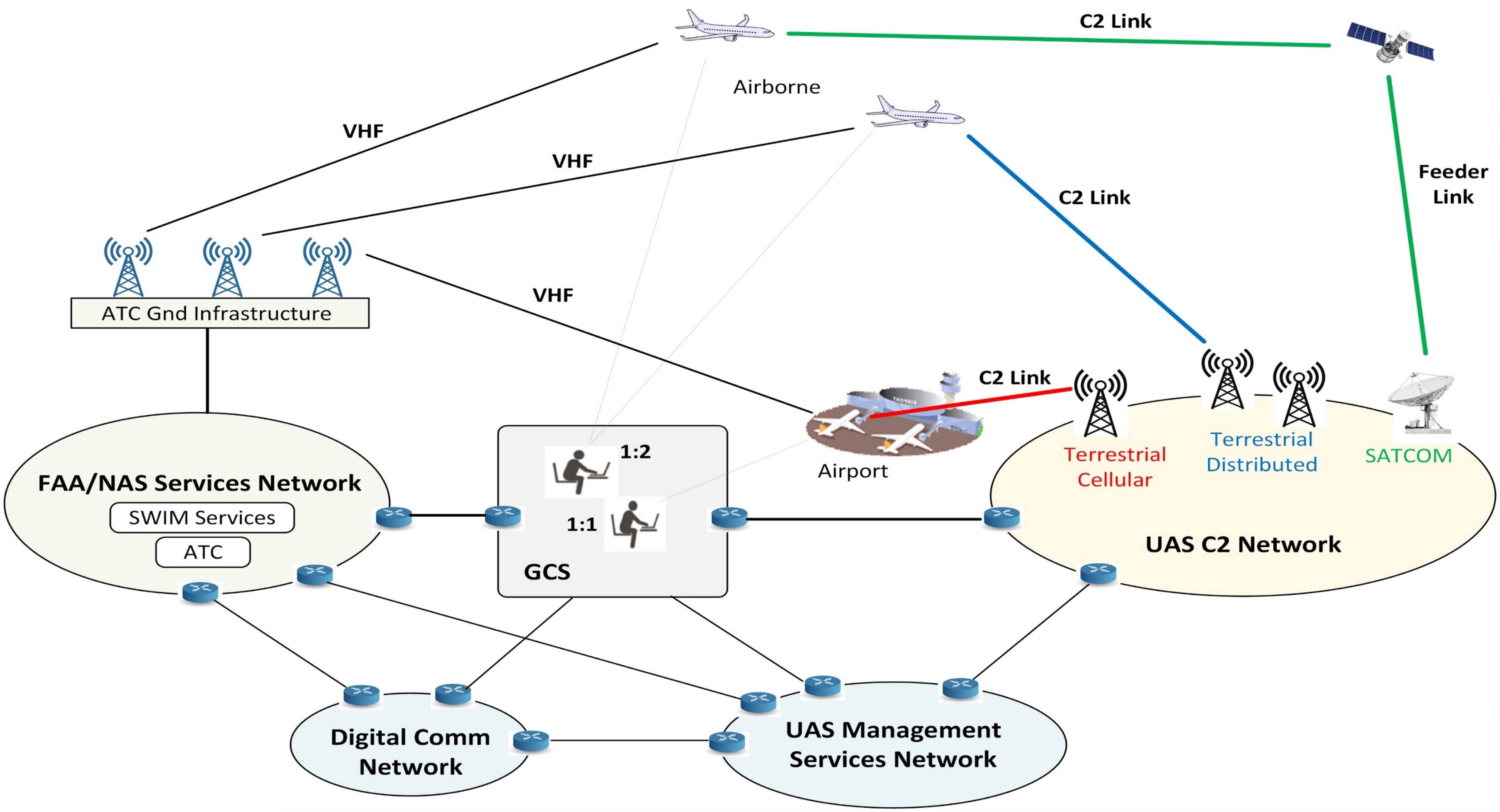


Architecture Concepts Description

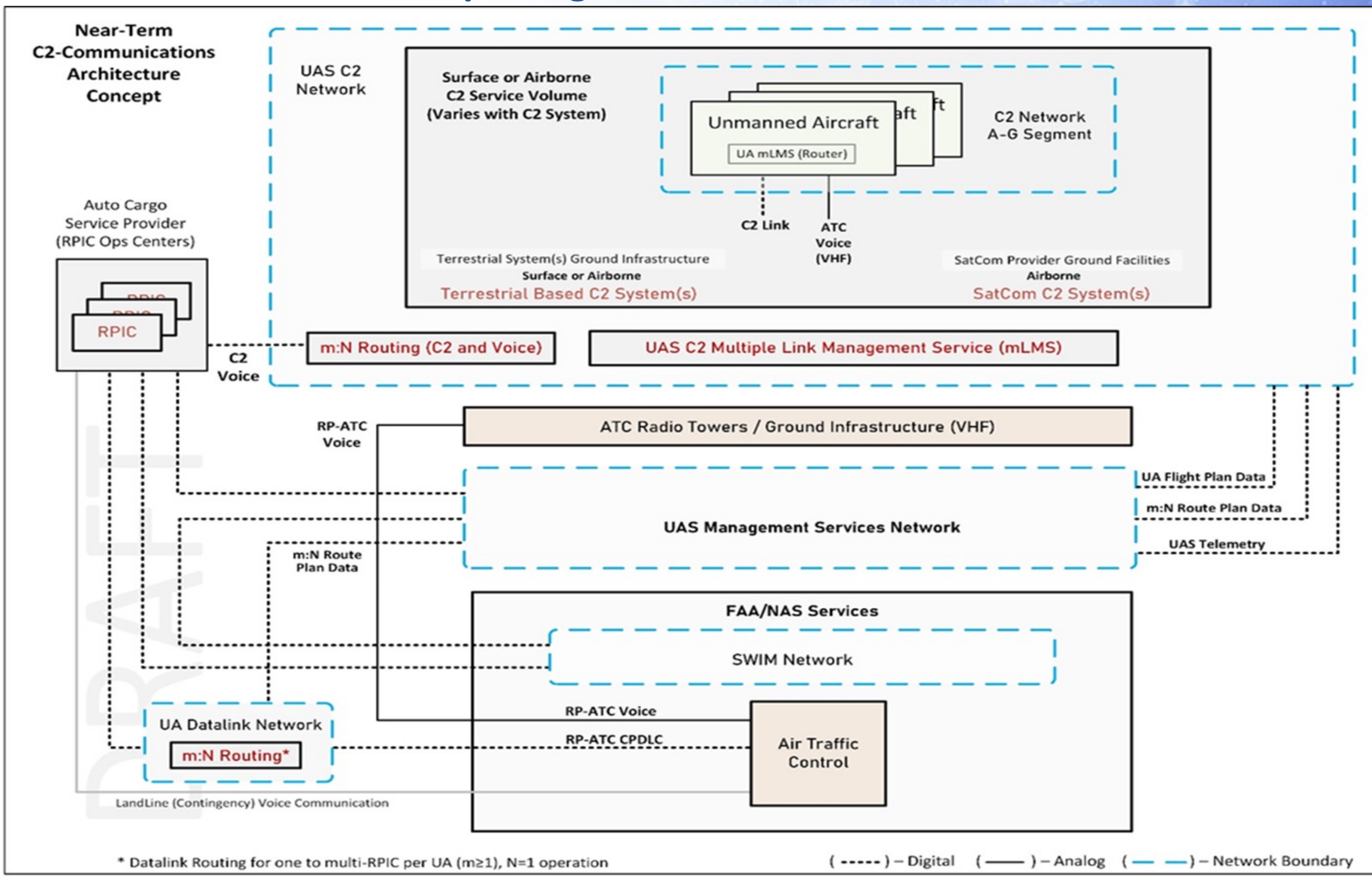
Remaining Agenda

- Operational View
- Overall Near-term Architecture
  - NT C2 Subsystem
  - NT Voice and Datalink Subsystem
- Overall End-state Architecture
  - ES C2 Subsystem
  - ES Voice (VoIP) and Datalink Subsystem
- Common Subsystems (in NT and ES)
  - UAS Management Services Subsystem
  - FAA/NAS Services Subsystem
- Subsystems/Services Interoperability

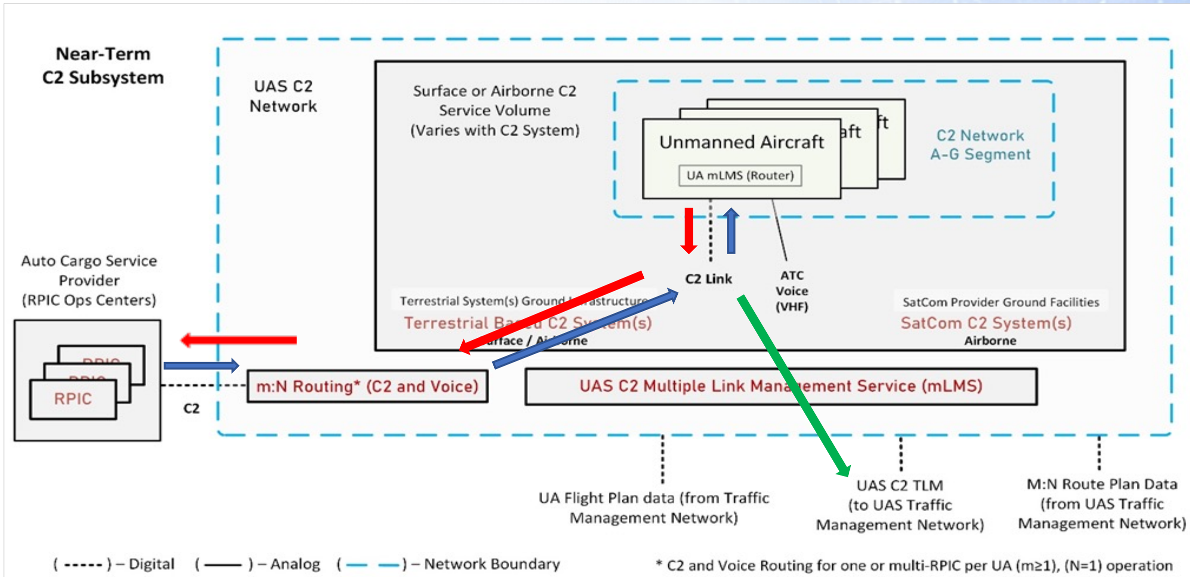
C2-Communication Architecture – Operational View



Near-term Architecture Concept Diagram

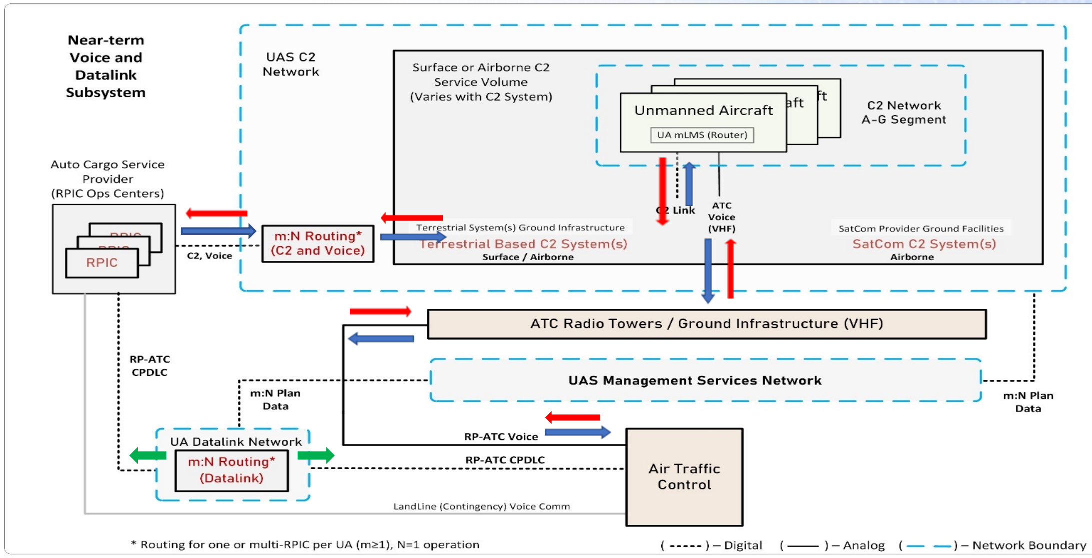


Near-term Architecture Concept – C2 Subsystem



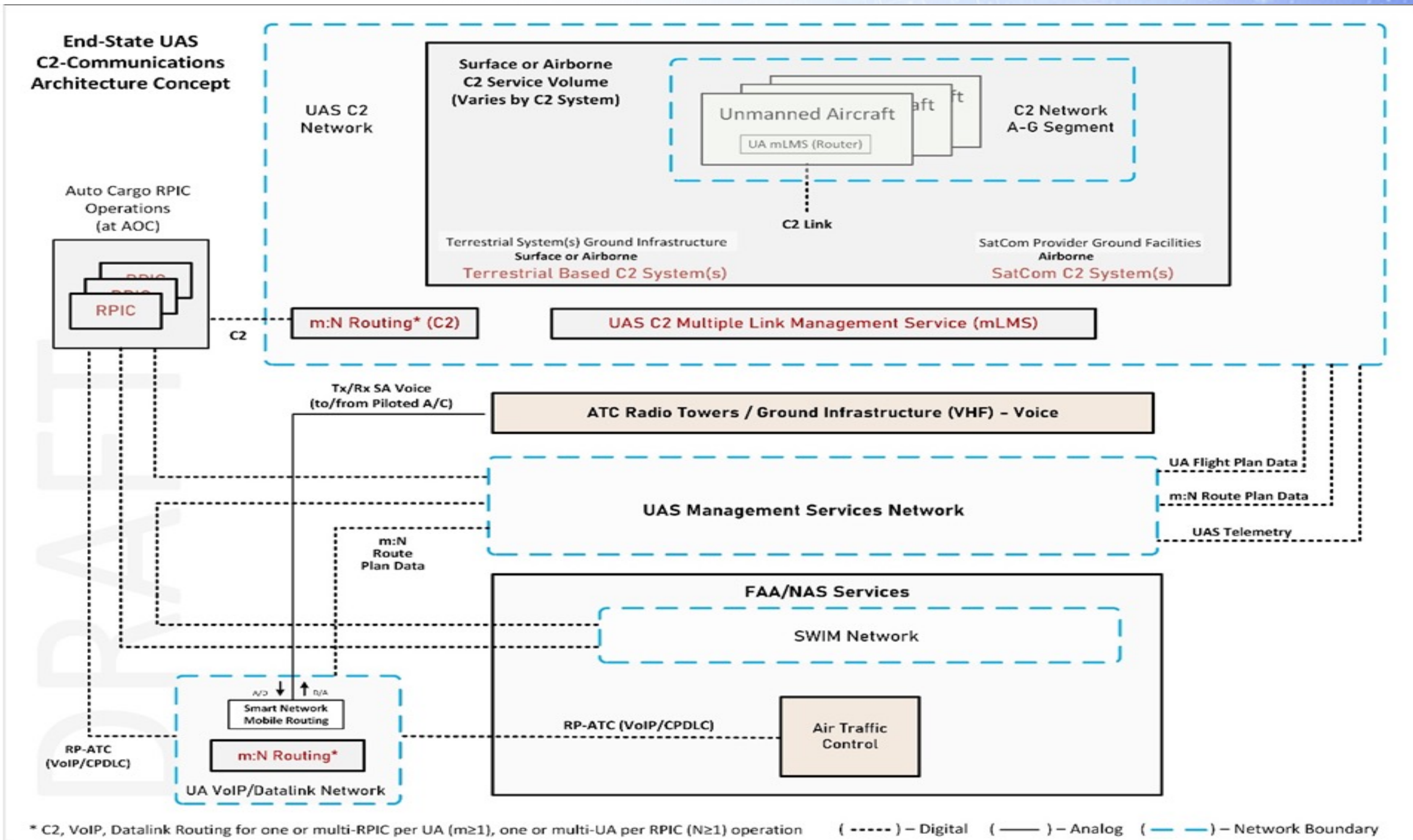
- NT C2 Subsystem identifies Multiple, interoperable, C2 Link systems – Terrestrial Cellular, Terrestrial DO-362, SatCom
- C2 Subsystem: 1) Delivers **RPIC to UA Commands** (to FMS and all systems onboard UA), 2) returns **Command Responses** from UA to RPIC, and provides **UA TLM Download**.
- Multiple Link Management Service (mLMS) – provides planning for C2 system switchovers and terrestrial C2 system frequencies for each UA flight.
- m:N Routing component (for **m≥1:N=1**) – manages RPIC–UA Command and Command Response Routing.
- All functions of the C2 Subsystem operate using a UAS C2 Network (Ground and A-G segments)

Near-term Architecture Concept – Voice and Datalink Subsystem



- NT Architecture uses UA-Relay for RPIC-ATC Voice
  - **RPIC-ATC**: RPIC voice packet → UAS C2 Network/m:N Router → C2 System/C2 UpLink → UA → ATC Tower → ATC
  - **ATC-RPIC**: ATC → ATC Tower → UA → C2 Downlink/C2 System → UAS C2 Network/m:N Router → RPIC
  - Situation Awareness – 1) RPIC messages transmitted to Airspace, 2) Piloted A/C messages sent to RPIC via C2 Link.
- **Datalink** is ground-based - communicates RPIC-ATC CPDLC messages using a dedicated UA Datalink Network.
- m:N Routing Components (for **m≥1:N=1**) – Used for Voice message and Datalink message routing.
  - Voice - Routes RPIC - ATC Voice to assigned RPIC(s). Operates within UAS C2 network.
  - RPIC – ATC Datalink Routing function. Operates within a dedicated Datalink network
- Maintains a contingency landline for voice comm if necessary.

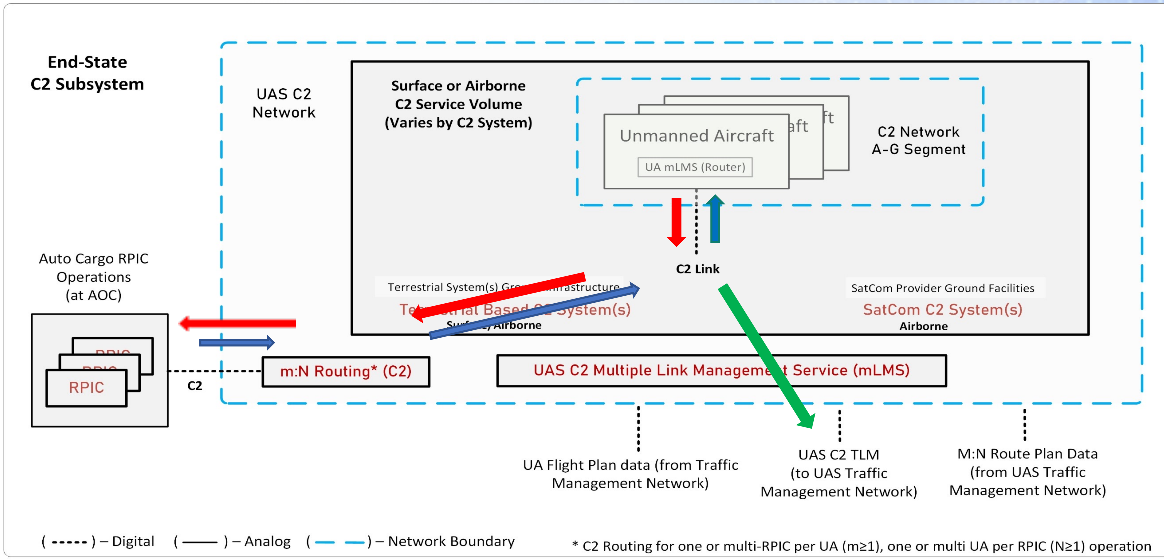
End-state Architecture Concept Diagram



End-state Concept – C2 Subsystem

Changes from NT

- C2 only (No voice)
- m:N routing matures for N>1
- Possible C2 System Upgrades expect updates to C2 technologies



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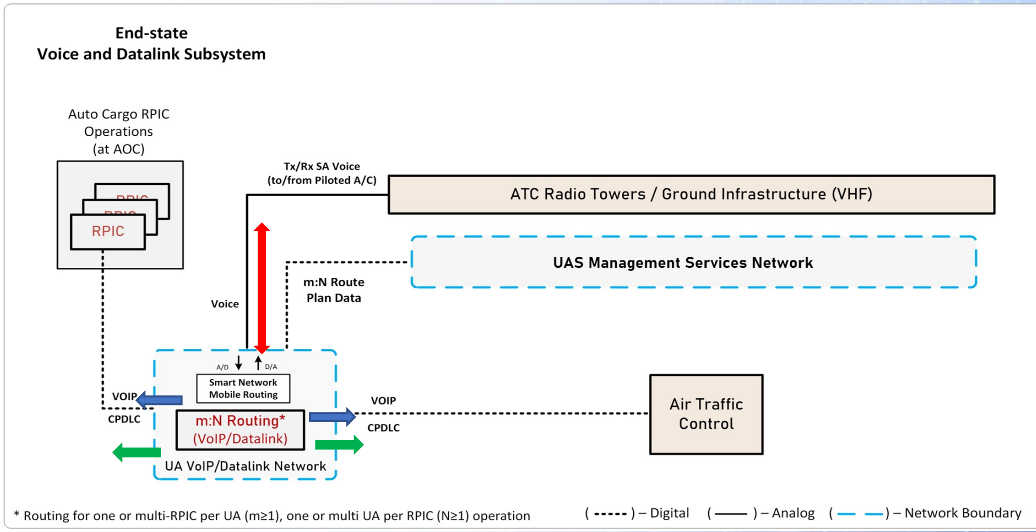
- C2 Subsystem: 1) Delivers **RPIC to UA Commands** (to FMS and all systems onboard UA), 2) returns **Command responses** from UA to RPIC, and provides **UA TLM Download**.
- Multiple Link Management Service (mLMS) – provides planning for C2 system switchovers and terrestrial C2 system frequencies for each UA flight.
- m:N Routing Component (for **m≥1:N≥1**) – RPIC Command and Command Response Routing component.
- All functions of the C2 Subsystem operate using a UAS C2 Network (Ground and A-G segments)

End-state Concept – Voice (now VoIP) and Datalink Subsystem

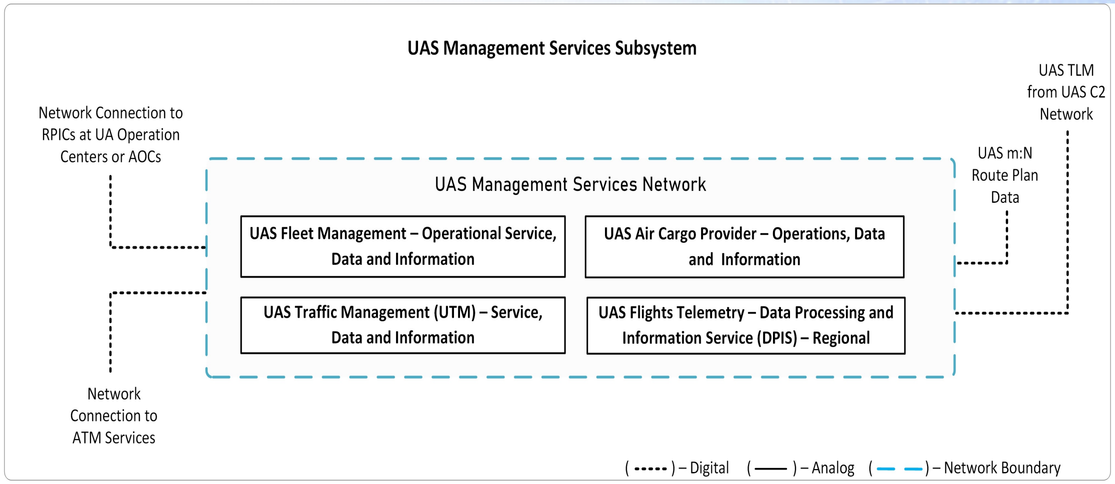
Changes from NT

- Datalink ground network updated to VoIP/Datalink Network
- RPIC-ATC voice via VoIP.
- m:N Routing for VoIP is is ground based and updated for N>1.
- Paralleled VoIP/VHF for SA



- **RPIC – ATC Voice (dialog) occurs using ground based VoIP** - voice no longer carried over the C2 link
  - Dedicated ground-based Datalink network upgraded to a VoIP/Datalink Network.
  - Smart Network parallel routing function introduced
    - Converts **RPIC or ATC VoIP to analog for parallel SA VHF transmission** in airspace.
    - Converts analog **piloted flight VHF to VoIP** (sent to RPIC) for SA.
- **Datalink** is ground-based - communicates RPIC-ATC CPDLC messages using a dedicated UA Datalink Network.
- Ground based m:N Routing Component (for **m≥1:N≥1**)
  - RPIC - ATC VoIP and Datalink Routing function. Operates within VoIP/Datalink ground network.
- Benefits: C2 link system freed up from voice message relay, conserves bandwidth and eliminates UA Voice Relay latency.

UAS Management Services Subsystem

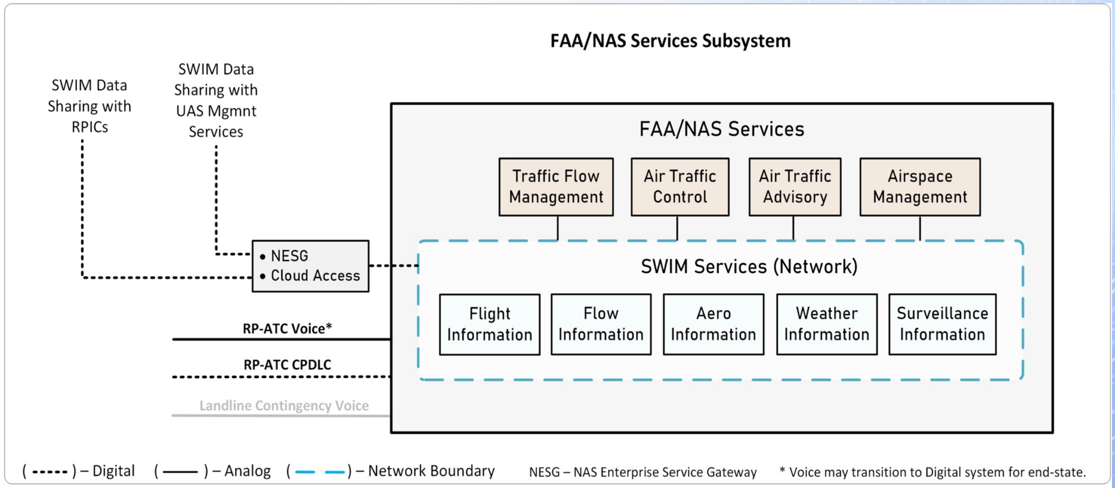


UAS Management Services - will facilitate safe, efficient UAS Service Provider operations (e.g. Air Cargo services, Air-taxi services, etc…)

- Provides Cooperative, Collaborative and Coordinated sharing of info and data for air traffic, fleet ops, and general operations.
- UAS Traffic Management Service for active UAS flight operations – general service for all UAS.

- Includes a Data Processing and Information Service (DPIS) for processing and secure dissemination of UAS Telemetry data.
- Appropriate partitioning of information to ensure proprietary business critical data is kept private. (publish-subscribe)
- All UAS Management Services operate within a dedicated Management Services Network
  - High performance, secure network - provide information centric operations with ubiquitous access to operators and service providers

FAA/NAS Services Subsystem



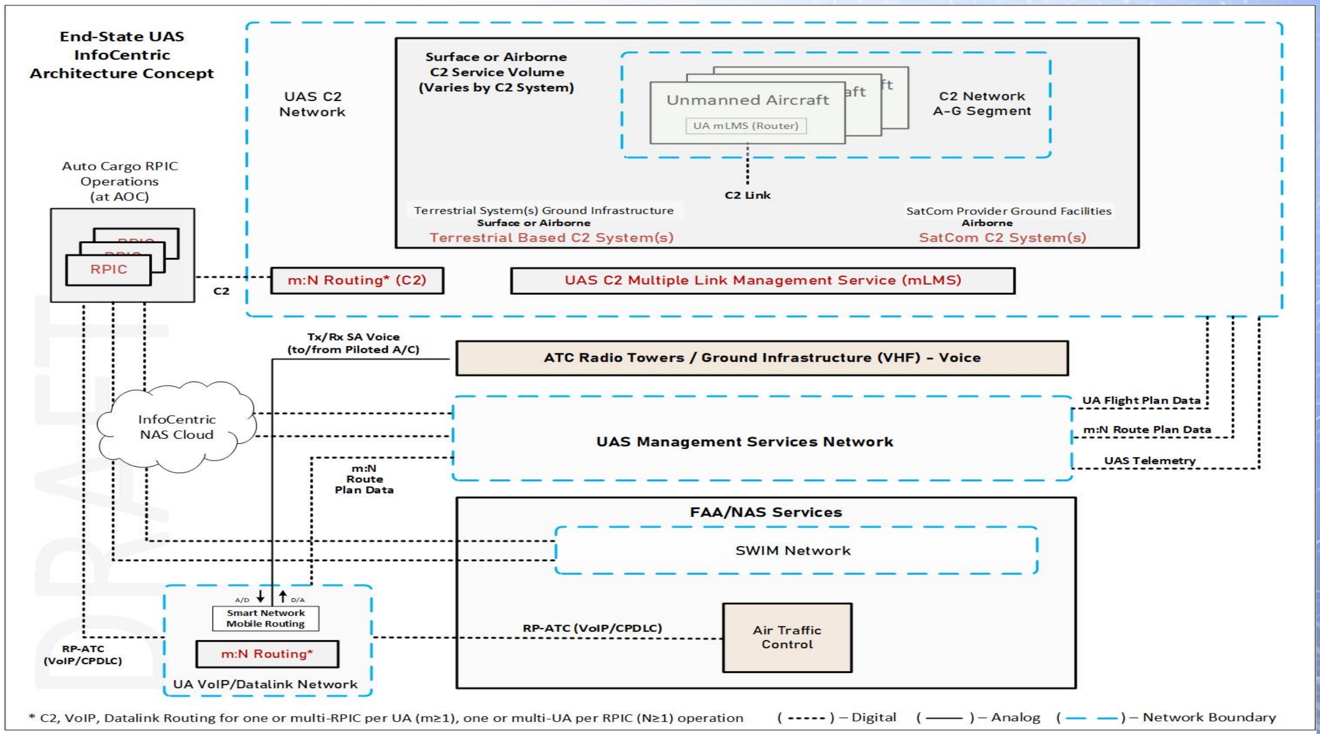
FAA/NAS Services – Air Navigation Service provision to Airspace Users

- Safe Separation of Aircraft
- Orderly Flow of Aircraft to address demand/capacity imbalances
- Efficient Management of Airspace

System Wide Information Management (SWIM) Services – Data and Information resulting from provision of FAA/NAS Services.

- Data and Information from Flight Plans and Flight Tracks
- Strategic data and information about Traffic Flow Management Initiatives
- Aeronautical Information (Special Activity Airspace, NOTAMs, Airport Configurations, etc)
- Observations, forecasts and graphical displays of current and forecasted weather.

End State Architecture in an InfoCentric NAS



- The FAA vision of the NAS information infrastructure increasingly leverages commercial assets, services, and new technologies in support of operations across diverse traffic management services
- With all types of devices connected to the Internet and advances in wireless technology, nearly everything can be connected from nearly any location at any time.
- This public and private infrastructure delivers traffic management services that are ubiquitous (available everywhere and always), resilient to unanticipated changes, and agile to respond to future user needs.
- InfoCentric NAS Cloud will be compliant with FAA initiative for Zero Trust strategy for Cyber Security.

Summary

- Presented our concept for transitional architecture (Nerm-term to End-state)
- Presented ideas within the architecture for Interactive UA – NAS – Third Party UA Services operations.
- Presented several ideas for new functional elements of the architecture that need evaluation and research (e.g. combined ground Datalink and VoIP Network, mLMS, m:N Routing, etc…)

What's Next (on our agenda)

- Complete Draft of C2-Communications Concept Document by 9/30/23

QUESTIONS ??

Other slides

m:N Manager Routing - NT vs ES Operations Summary

Near-term m:N Functions

- C2 and Voice - Routes m≥1:N=1, C2 (commands and command responses) + bidirectional, RPIC-ATC, digitized Voice messages between the RPIC and UA. Operates within the UAS C2 Network.
- Datalink function - Routes m≥1:N=1, bidirectional RPIC-ATC Datalink messages between the RPIC and ATCo. Operates within a ground-based UA Datalink Network.

End-state

- C2 - Routes m≥1:N≥1, C2 (commands and command responses) between the RPIC and UA. Operates within the UAS C2 Network.
- VoIP and Datalink – Routes m≥1:N≥1, bidirectional RPIC-ATC, VoIP and Datalink messages between the RPIC and ATCo. Operates within a ground-based, UA VoIP/Datalink Network.

Note: Synchronization of m:N components in the C2 subsystem and VoIP/Datalink subsystem will need to be carefully managed. Require consistent/timely m:N data updates to function.