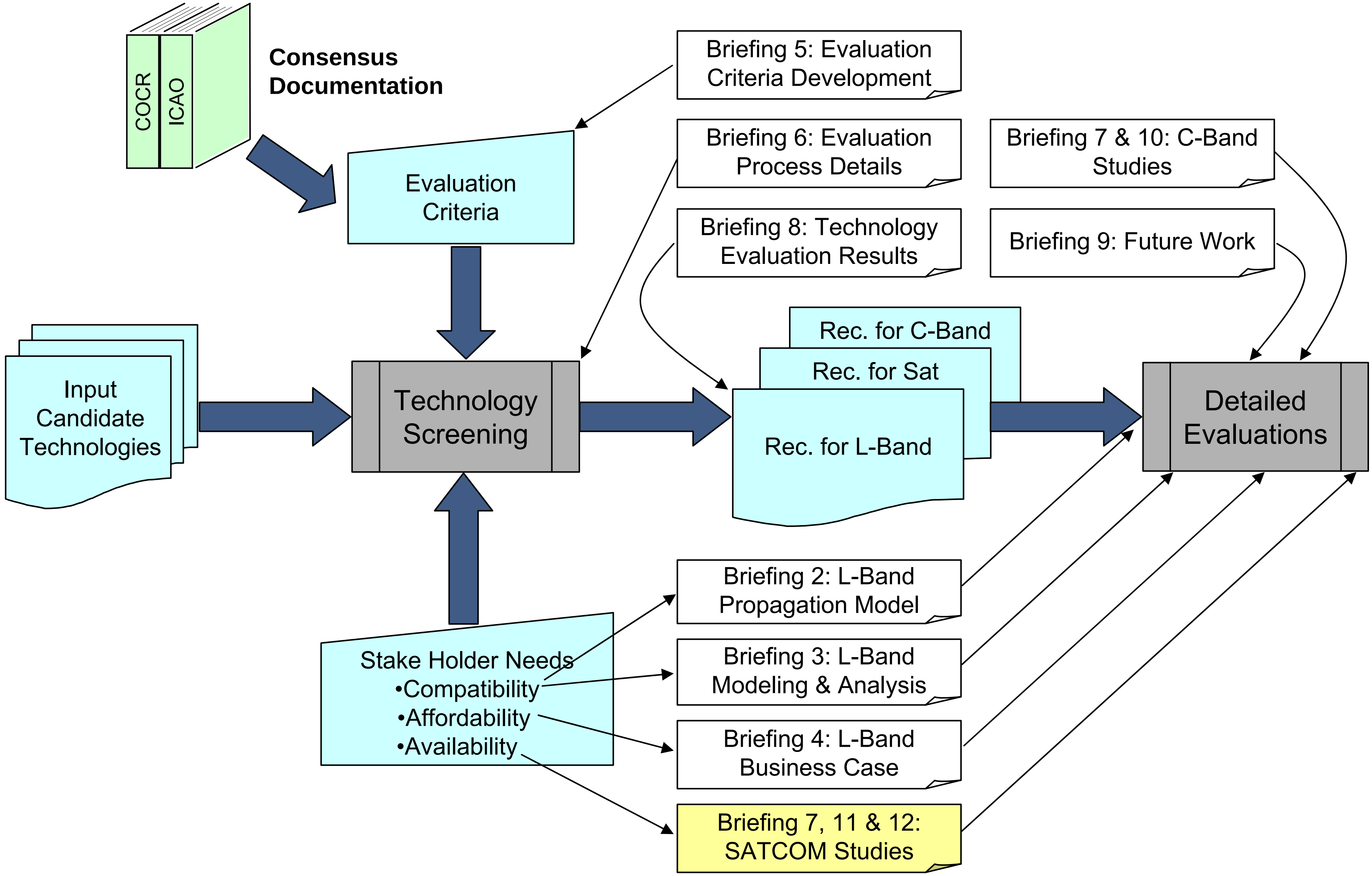
Briefing #12 - COCR Service Provisioning Using SATCOM & Hybrid Architectures

Future Communications Study

Phase II End of Task Briefing

June 22, 2006

Structure and Content of the Presentations



Outline

- Objectives
- Identification of SATCOM Architectures Investigated
- COCR Availability Requirements
- COCR Service Provisioning over SATCOM
- Evaluation of Hybrid SATCOM Architectures

Objectives

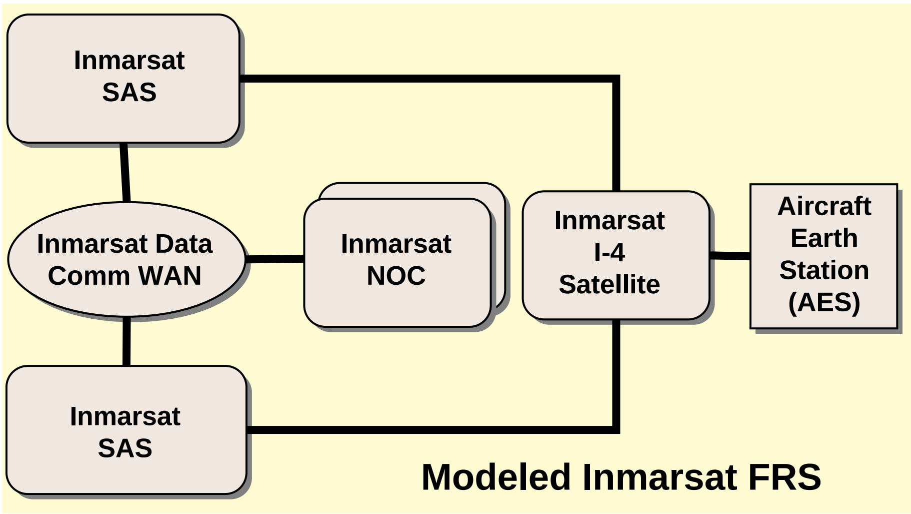
Objectives

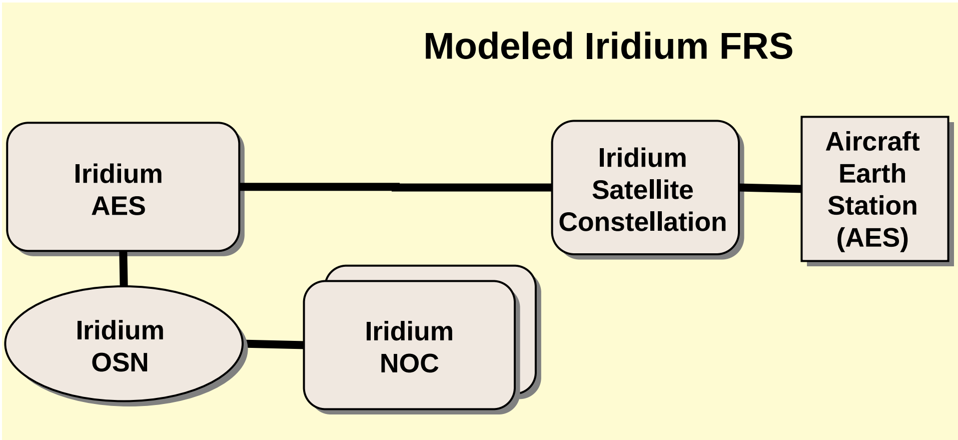
- Overall SATCOM Study Objectives:
  - The satellite studies tasks (briefings 11 & 12) primarily support the detailed investigation of candidate technologies for the Future Radio System
    - Evaluate availability of SATCOM technology candidates Inmarsat SBB and Iridium
    - Determine if SATCOM technology candidate architectures can meet COCR requirements
    - Compare/contrast the performance of current SATCOM data service offerings with AMS(R)S allocations with existing/representative terrestrial data services
- This briefing:
  - Examines the provisioning of COCR services over Inmarsat SBB and Iridium with respect to availability performance
  - Provides a high-level analysis of hybrid SATCOM architectures

Identification of SATCOM Architectures Investigated

Investigated SATCOM Technologies

- Investigated SATCOM technologies include Inmarsat SBB and Iridium
  - Only current SATCOM offerings within the FCS technology inventory with AMS(R)S spectrum allocations
  - Associated architectures have been described in the previous briefing





COCR Availability Requirements

COCR Availability Requirements

- The COCR identifies the following types of performance requirements
  - Data capacity
  - Latency
  - QoS
  - Number of Users
  - Security
  - Availability
- Availability was not explicitly investigated as part of the FCS Phase II technology evaluation
  - Availability is an architecture design factor, and the majority of the investigated technologies are not associated with a specific architecture
    - During system design, appropriate performance/cost trade-offs would be performed
- The evaluated SATCOM technologies do have defined architectures
  - Availability **<u>can be explicitly considered</u>**
    - This is important as the SATCOM availability metric is a potential driver in determining applicability of the technology to COCR service provisioning

COCR Availability Requirements (2)

- COCR version 1.0 indicates specified availability for the FRS is based on availability parameters (and associated definitions) provided in RTCA DO-290
  - Two parameters are specified
    - Availability of Use (A_U): Probability that the communication system between the two parties is in service when it is needed
    - Availability of Provision (A_P): Probability that communication with all aircraft in the area is in service

COCR Availability Requirements (3)

- In the COCR, the A_U is specified as two orders of magnitude less than A_P when A_P is greater than 10^{-7}; otherwise A_U is specified as one order of magnitude less than A_P
  - A_u addresses connectivity to a user and includes user installations that are part of the communication link
    - Appropriate for single user availability calculations that account for the aircraft station availability
  - A_P is a requirement on the air traffic service provider
    - Appropriate for multi-user availability calculations that focus on service provision to an entire service volume (and do not account for individual aircraft station availability contributors)
    - The focus of this analysis is multi-user availability, thus the focus is on A_P requirements

COCR Availability Requirements (4)

- COCR Service Availability Requirements:
  - ATS A_P requirements:
    - Phase I: 0.9995
    - Phase II:
      - With A-EXEC: Range from .9995 to .9999999995 [or $(.9)_9 5$]
      - Without A-EXEC: Range from .9995 to .99999995 [or $(.9)_7 5$ for PAIRAPP, ACL, ACM]
  - AOC A_P requirements:
    - Phase I & II: Range from .9995 to .999995 [or $(.9)_5 5$]

COCR Phase I Availability Requirement Examples

Service	Latency (RCTP - 1 way)					Integrity	Availability	
	APT	TMA	ENR	ORP	AOA			
	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$I_{UCT\text{-}FRS}$	$A_{P\text{-}FRS}$	$A_{U\text{-}FRS}$
ACL	3.8	3.8	3.8	26.5	-	5.0E-6	0.9995	0.9965
ACM	3.8	3.8	3.8	26.5	-	5.0E-6	0.9995	0.9965
ADS-B	0.80	4.8	9.6	9.6	-	5.0E-6	0.9995	0.9965
A-EXEC	-	-	-	-	-	-	-	-
AIRSEP	-	-	-	-	-	-	-	-
AMC	3.8	3.8	3.8	26.5	-	5.0E-4	0.9995	0.9965
ARMAND	-	-	9.2	-	-	5.0E-6	0.9995	0.9965
C&P	-	3.8	3.8	26.5	-	5.0E-6	0.9995	0.9965

COCR Phase II Availability Requirement Examples

Service	Latency (RCTP - 1 way)					Integrity	Availability	
	APT	TMA	ENR	ORP	AOA			
	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$I_{UCT\text{-}FRS}$	$A_{P\text{-}FRS}$	$A_{U\text{-}FRS}$
ACL	1.4	1.4	1.4	1.4	1.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
ACM	1.4	1.4	1.4	2.4	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
ADS-B	0.8	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
A-EXEC	-	0.74	0.74	0.74	-	5.0E-10	1-(5.0E-10)	1-(5.0E-8)
AIRSEP	-	-	-	-	8.0	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
AMC	1.4	1.4	1.4	1.4	1.4	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
ARMAND	-	-	4.7	-	-	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
C&P	-	2.4	2.4	2.4	-	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
COTRAC	-	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
D-ALERT	2.4	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)

COCR Service Provisioning over SATCOM

SATCOM Availability Performance

- Briefing #11 identifies availability contributors and analysis results for Inmarsat SBB/Iridium architectures
  - Availability estimates vary widely with availability contributors
    - For Inmarsat, individual availability contributor values range from .95 to 1
    - For Iridium, calculated availability contributors range from .995 to 1

	System Component Failures				Fault-Free Rare Events			
	Ground Station	Control Station	Aircraft Station	Satellite	RF Link	Capacity Overload	Interference	Scintillation
Inmarsat	***~ 1***	***~ 1***	***~ 1***	***0.9999***	***0.95***	***~ 1***	***~ 1***	***~ 1***
Iridium	***0.99997***	***~ 1***	***~ 1***	***0.99***	***0.995***	**-** [1]	***0.996***	***~ 1***
VHF Terrestrial	***0.99999***	N/A	***~ 1***	N/A	***0.999***	***~ 1*** [2]	***~ 1***	N/A

Notes:

1. For Iridium, Terrestrial Capacity Overload availability of downlink traffic is approx 1 (for both ATS only and ATS & AOC). No steady-state can be achieved for uplink traffic
2. Terrestrial Capacity Overload availability is for L-Band reference architecture business case; for VHF Terrestrial Capacity Overload availability would be insufficient

SATCOM Availability Performance (2)

- Inmarsat/Iridium *may* provide sufficient availability performance to meet a subset COCR service availability performance requirements in limited applications
- It is clear, however, that these SATCOM architectures will not provide sufficient availability to provision most if not all of the COCR services defined for Phase II operations

SATCOM Availability Performance (3)

- The described results are in line with other recent studies that have investigated Inmarsat/Iridium availability performance
  - EUROCONTROL – Inmarsat SBB Services for Air Traffic Services
    - No explicit calculation of availability, but indication that this service is not sufficient as a standalone solution for ATS
  - Boeing Team - GCNSS – Phase I
    - Availability analysis was undertaken for a proposed architecture for NAS ATS
      - Individual calculation details not available
    - However, to meet availability requirements, recommended architecture includes ***five*** satellite infrastructure

COCR Service Provisioning over SATCOM

- Results indicate that Inmarsat SBB and Iridium will not provide sufficient availability to provide a stand alone solution for the future radio system
  - These SATCOM systems may provide a meaningful role in specific domains (e.g. oceanic/remote) and/or specific, limited applications (e.g. disaster recovery)
  - This does not preclude consideration of other SATCOM systems to provide a wider role in provisioning ATS services
    - Proposed architectures, for example SDLS, may be designed specifically for ATS and with architectures specifically engineering to meet all COCR requirements

Evaluation of Hybrid SATCOM Architectures

Hybrid SATCOM Architectures

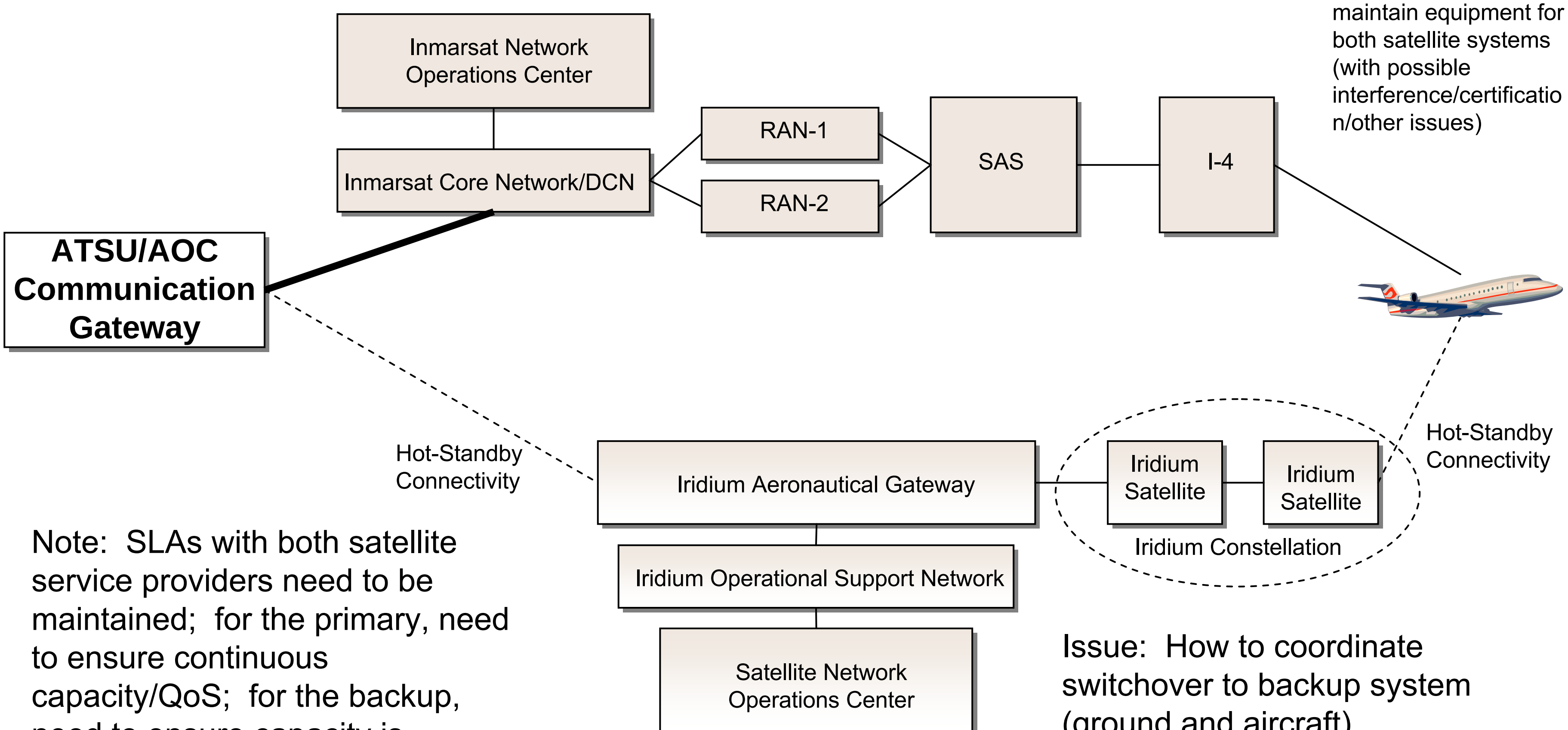
- Note that the current aeronautical communication infrastructure can be considered a hybrid architecture
  - Continental communications are provided by terrestrial architectures; oceanic/remote are provided by satellite and/or HF data link architectures
  - Limited use of SATCOM systems (e.g. FAASAT) have been used for temporary recovery situations (e.g. Katrina) and for circuit backup
- Given that the evaluated SATCOM architectures (as stand-alone solutions) may not sufficiently provision the complete set of COCR services, consideration of the current hybrid architecture environment and other possible hybrids has been considered
  - Many possibilities exist, including SATCOM/SATCOM hybrids and SATCOM/terrestrial hybrids
  - Several were selected for qualitative evaluation and comparison

Hybrid SATCOM Architectures

Architecture Name	Description	Rationale for Further Consideration
1. Dual GEO/LEO Satellite Architecture	GEO satellite architecture backup to LEO architecture or vice versa	**Evaluated Further – specifically identified in SOW**
2. Terrestrial with Satellite Backup	Terrestrial network that has "stand-by" access to a backup satellite network	Not Considered: Disaster Recovery use of satellite may be addressed by increasing the geographic-based coverage (from scenario 5 below); cost-prohibitive as a standalone solution
3. Satellite with Terrestrial Backup	Satellite service that has "stand-by" access to backup terrestrial network	Not Considered: Cost prohibitive to implement terrestrial "backup" network or to maintain capacity reserve in an existing terrestrial system to address a full satellite load
4. Shared services across joint terrestrial/satellite architecture	Full complement of service available to users from both terrestrial and satellite architecture components – fully redundant architecture	Note Considered: Requires maintaining two fully redundant systems to be used on demand; cost prohibitive, complex and no sizeable benefit over architecture 6 (static allocation of services to systems)
5. Geographic-based allocation of services across terrestrial/ satellite architecture	Terrestrial services are used in some areas of the service volume while satellite services are used in other areas of the service volume	**Evaluated Further – current operational Implementation**
6. Service-based allocation of services across terrestrial/ satellite architecture	Some services are provisioned over terrestrial services while others are provisioned over satellite services	**Evaluated Further**

Hybrid SATCOM Architectures (2)

- Dual GEO/LEO Satellite Communication Architecture



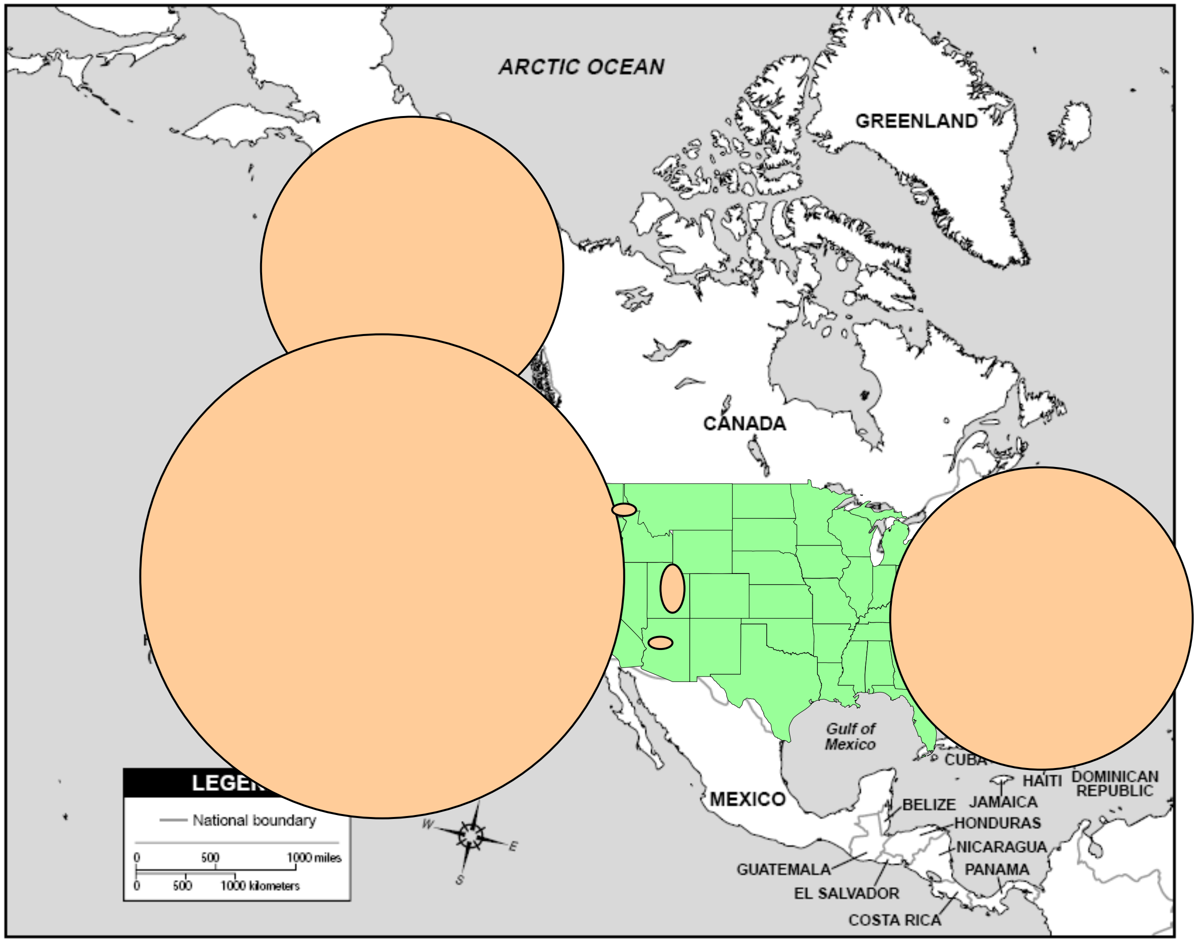
Note: Aircraft need to maintain equipment for both satellite systems (with possible interference/certification/other issues)

Note: SLAs with both satellite service providers need to be maintained; for the primary, need to ensure continuous capacity/QoS; for the backup, need to ensure capacity is available for backup scenarios

Issue: How to coordinate switchover to backup system (ground and aircraft)

Hybrid SATCOM Architectures (3)

- Geographically-Based Terrestrial/Satellite Communication Service Architecture



Green – Terrestrial Service
Orange – Satellite Service

Notes:

1. Aircraft that stay within CONUS need only to maintain the terrestrial communication equipment; those aircraft with participation in oceanic/remote airspace need to maintain equipment for both satellite and terrestrial-based ground systems
2. This scenario is in operation today

Hybrid SATCOM Architectures (4)

- Service-Based Terrestrial/Satellite Communication Service Architecture

- COCR Services over Terrestrial Communication Services
  - ATS Services
    - Controller/Flight Crew Services (e.g. ACL, AMC, D-TAXI, DCL, DSC, PPD, DYNAV)
    - Traffic & Surveillance
    - Emergency and Ancillary (URCO and D-ALERT)
    - Communication Management (DLL and ACM)
    - Auto-Downlink and FIS in Airport Domain
  - AOC Services
    - Services allocated in some flight domain to service class J (most stringent AOC service class)
      - Includes Login, OOOI, Flight Status, Gate Info, Maintenance, Flight Plan, Loadsheet, Graphical Weather and Real-Time Weather

- COCR Services over Satellite Communication Services
  - ATS Services (when not in airport domain)
    - Automated Downlink of Airborne Parameters
      - Includes FLIPCY, FLIPINT and SAP
    - Flight Information Services
      - Includes D-OTIS, D-RVR, D-ORIS, D-SIGMET, D-ATIS, D-FLUP, D-SIG
  - AOC Services
    - Services not included in service class J and not in the airport domain
      - Includes NOTAMs, Free Text, Position Report, Fuel Status, Engine Performance, Flight Log, Real-Time Maintenance, etc.

Notes: 1) SLAs with satellite service provider need to be maintained; and connectivity provided between appropriate ground systems and satellite ground interface; 2) Aircraft need to equip with both terrestrial-based and satellite-based communication systems (when ATS services are mandated)

Issue: Coordinate switchover of received data from terrestrial to satellite system when leaving airport domain (for services that are existing in airport domain but serviced by SATCOM system outside the airport domain)

Evaluation of Hybrid Architectures

- A ***qualitative*** comparative analysis of candidate hybrid architectures was made based on the following criteria
  - Meets COCR service functional requirements
    - Considers ability to provide required service connectivity (e.g. A-G, A-A, etc), service domains (e.g. En Route, O/R/P, etc), addressed vs. broadcast, etc
  - Meets COCR service performance requirements
    - General considerations for availability, latency, QoS and security
  - Relative Ground Infrastructure/Airborne Installation Cost
  - Relative Technical Risk
  - Relative Benefits

Evaluation of Hybrid Architectures – Functional Requirements

	Function/Service				Notes
	ATS A/G & G/A Addressed	ATS Ground Broadcast	ATS A/A Addressed	AOC A/G & G/A Addressed	
A. Dual GEO/LEO Satellite Architecture	√	√	√	√	This architecture is capable of addressing the functional communication requirements of the COCR for ATS and AOC services
B. Geographic-Based Allocation of Services	√	√	√	√	This architecture is capable of addressing the functional communication requirements of the COCR for ATS and AOC services
C. Service-Based Allocation Across Terrestrial/ Satellite Architecture	√	√	√	√	This architecture is capable of addressing the functional communication requirements of the COCR for ATS and AOC services;

Evaluation of Hybrid Architectures – Performance Requirements

	Performance					Additional Notes
	Number of Users	Data Rate		QOS	Availability	
		ATS - only	ATS & AOC			
A. Dual GEO/LEO Satellite Architecture	√	√	√	Unclear	Partial	With parallel operation of the SATCOM systems, assuming availability on the order of .999 for each system, the total availability is on the order of .999999, which provides similar capabilities to terrestrial architectures, and can meet all Phase I COCR availability requirements and some requirements for Phase II (e.g. FIS services, but not A/A service requirements)
B. Geographic-Based Allocation of Services	√	√	√	Partial	Partial	The SATCOM architecture offerings (as estimated in this study) do not alone meet the stated service provisioning requirements of the COCR (Phase I and II); thus the geographic areas allocated to satellite may not meet all performance requirements. For those regions allocated terrestrial systems, it is anticipated that appropriate design of the system can led to meeting all Phase I and II COCR requirements. It should be noted that one Phase II service (A-EXEC) has a very high availability requirement that in and of itself could drive architecture design and cost. With this service, the terrestrial architecture required to meet performance would likely be prohibitively expensive; without it, an architecture with redundancies more similar to today's terrestrial aeronautical systems could be utilized to satisfy COCR requirements.
C. Service-Based Allocation Across Terrestrial/ Satellite Architecture	√	√	√	Partial	Partial	For the selected representative architecture, the capacity, data rate and number of users parameters can likely be addressed during architecture design. The QoS provisions for SATCOM aeronautical offerings are not fully described and it is unclear if required QoS provisioning will be met. The SATCOM architecture offerings (as estimated in this study) do not alone meet the state service provisioning requirements of the COCR (Phase I and II); thus the services allocated to satellite may not meet all performance requirements. For those services allocated terrestrial systems, it is anticipated that appropriate design of the system can led to meeting all Phase I and II COCR requirements. It should be noted that one Phase II service (A-EXEC) has a very high availability requirement that in and of itself could drive architecture design and cost. With this service, the terrestrial architecture required to meet performance would likely be prohibitively expensive; without it, an architecture with redundancies more similar to today's terrestrial aeronautical systems could be utilized to satisfy COCR requirements.

Evaluation of Hybrid Architectures – Relative Cost

Architecture Name	Applicable Factors	Relative Cost Estimate	Additional Notes
A. Dual GEO/LEO Satellite Architecture	• Ground infrastructure: connectivity to two satellite gateways; • Aircraft installation: includes two satellite transponders (one for each system)	***High***	On the ground, connectivity with two SATCOM service providers and SLAs for sufficient communication capacity requires a high relative cost as compared to a non-hybrid system; aircraft installation requires a high relative cost as compared to a non-hybrid system as multiple SATCOM equipment is required. This solution may have a similar relative cost to architecture C, but perhaps greater than architecture B, which does not require all aircraft to have dual system equipage.
B. Geographic-based allocation of services across terrestrial/ satellite architecture	• Ground infrastructure: connectivity to terrestrial communication systems for CONUS and satellite gateways (from control facilities that are responsible for geographic areas allocated to SATCOM) • Aircraft Installation: Those aircraft that fly in regions allocated to SATCOM, include both SATCOM and Terrestrial COM transceivers; aircraft that do not participate in geographic regions allocated SATCOM do not require SATCOM transceiver equipage	***Moderate***	On the ground, connectivity is typically with one communication system; for facilities responsible for CONUS operations, the communication system is terrestrial, while for oceanic, it is a SATCOM system. Moderate cost is required to implement new systems and connectivity. For aircraft equipage, again the cost is moderate. Its relative cost is greater that non-hybrid configurations; however only aircraft participating in geographic areas designated for SATCOM require dual system equipage. This solution is likely to have a lower relative cost as compared to architectures A and C.
C. Service-based allocation of services across terrestrial/ satellite architecture	• Ground infrastructure: requires connectivity to both terrestrial and satellite ground infrastructure • Aircraft installation: all aircraft require both terrestrial-based and SATCOM-based communication transceivers	***High***	On the ground, connectivity with both a terrestrial and SATCOM service provider/system requires a high relative cost as compared to a non-hybrid system; however, it may support longer life for initially deployed low data rate data communication systems. Aircraft installation requires a high relative cost as compared to a non-hybrid system as both terrestrial-based and SATCOM based transceivers are required. This solution may have a similar relative cost to architecture A, but perhaps greater that architecture B, which does not require all aircraft to have dual system equipage.

Evaluation of Hybrid Architectures – Technical Risk

	Factor				Overall Assessment
	Transition	Switchover to Backup	Ground Infrastructure	Airborne Implementation	
A. Dual GEO/LEO Satellite Architecture	This architecture represents a new concept for NAS ATC; transition would likely be complex (high risk)	Switchover between primary SATCOM and backup SATCOM would be complex both for ground and aircraft installations (high risk)	Need to design and implement interfaces to multiple SATCOM GES, NOCCs etc. but could be engineered (modest risk)	Need aircraft architecture that can operate and accommodate ATS and AOC traffic across a primary/backup architecture with two distinct SATCOM systems (moderate risk)	***High Risk***
B. Geographic-Based Allocation of Services	Variants of this architecture are in use today. Transition could likely be engineered with low risk	Not applicable	Need to design and implement new interfaces to SATCOM and terrestrial systems (modest risk)	Similar to architectures in use today (low risk)	***Low Risk***
C. Service-Based Allocation Across Terrestrial/ Satellite Architecture	This architecture could be phased in and considered an extension to the type of SATCOM/ terrestrial architectures in use today (modest risk)	Not applicable	Need to design and implement new interfaces to SATCOM and terrestrial systems (modest risk)	Need to extend similar architecture in use today to accommodate dual active services across terrestrial and SATCOM systems (Moderate Risk)	***Moderate Risk***

Evaluation of Hybrid Architectures – Relative Benefits

	Factor			Assessment
	Capacity	Efficiency	Cost	
A. Dual GEO/LEO Satellite Architecture	Architecture accommodates communication functionality of COCR	May not be extremely efficient to maintain a SATCOM system and associated capacity as a "hot spare" (may be less efficient than other alternatives)	Use of SATCOM systems alone removes the need to implement new terrestrial infrastructure; however infrastructure to connect to the SATCOM ground network is required	***Low Benefit***
B. Geographic-Based Allocation of Services	Architecture accommodates communication functionality of COCR; however SATCOM allocations may not meet all COCR required performance; may be limited capacity improvement over current/planned implementation	Accommodates transition from existing similar architectures to slowly add capability and efficiency	May not be large efficiency improvement over existing/planned capabilities without significant costs	***Moderate Benefit***
C. Service-Based Allocation Across Terrestrial/ Satellite Architecture	Architecture accommodates communication functionality of COCR; however SATCOM allocations may not meet all COCR required performance	May provide a scenario to best use planned data communication infrastructure (e.g. VDL-2) while adding less critical services over a supplemental SATCOM architecture; this could be a significant benefit	Need to account for new infrastructure to connect to the SATCOM ground network; terrestrial infrastructure could be provided (at least initially and potentially fully) by planned terrestrial-based data link architectures (e.g. VDL-2)	***Moderate Benefit***

Evaluation of Hybrid Architectures – Conclusions

- Analysis Summary

Architecture Name	Functional Capability	Performance Capability	Cost	Technical Risk	Benefit
A. Dual GEO/LEO Satellite Architecture	MEETS	PARTIALLY MEETS	HIGH	HIGH	LOW
B. Geographic-based allocation of services across terrestrial/satellite architecture	MEETS	PARTIALLY MEETS	MODERATE	LOW	MODERATE
C. Service-based allocation of services across terrestrial/satellite architecture	MEETS	PARTIALLY MEETS	HIGH	MODERATE	MODERATE

- Conclusions
  - There is a potential role for hybrid satellite architectures for aeronautical mobile communications
    - Role is not obvious; but an architecture that may satisfy multiple roles (e.g. provide capacity and emergency backup, such as provided by architectures B and C or a combination of the two) may be desirable
  - No one architecture is a stand-out
    - Architectures B and C (geographic-based and service-based allocation of services to terrestrial/SATCOM systems) appear to have greater potential that a SATCOM/SATCOM architecture (architecture A)