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1 Executive Summary

The Mobile Communication Network Architecture (MCNA) encompasses the aggregate of all voice and data communication capabilities in support of communications, navigation and surveillance (CNS) services for Air Traffic Management (ATM) operations. Like System Wide Information Management (SWIM), MCNA is a key enabling technology for transformation of the National Airspace System (NAS) towards Network Centric Operations (NCO).

1.1 MCNA Contract Overview

The MCNA development effort under the FAA's Global CNS System Phase II (GCNSS II) contract was co-funded by NASA Glenn Research Center (GRC) and the FAA. As such, it is closely associated with the overall goals of the GCNSS II contract to prepare the FAA for the introduction of SWIM into the NAS.

The Boeing Team applied a System of Systems Engineering (SoSE) approach to the evaluation of the evolving communications needs of the NAS. The Boeing team compiled air-ground (A-G) and air-air (A-A) communication requirements from many industry sources and evaluated them against existing and planned MCNA capabilities to identify gaps and/or inconsistencies that must be addressed either through the enhancement of current systems and capabilities or the development of new MCNA systems. The specific focus of this effort was the evaluation of the requirements, architecture and associated transition plan. Complementing these efforts were tasks evaluating the certification challenges MCNA introduces, the Simulation, Emulation, and Demonstrations needs to mitigate risks, and investment analysis to provide rationale for future investment in MCNA.

These activities were conducted from the perspective of assuring that the A-G and A-A communications capabilities will be compatible with, and supportive of, the needs of SWIM as necessary to enable NCO. The goal of this effort is to develop an integrated SoSE approach and resultant technology development roadmap. As shown in Figure 1 these artifacts are intended to provide guidance for ongoing and planned NASA Glenn Research Center (GRC) and FAA research activities including NASA GRC's Advanced CNS Architectures and System Technologies (ACAST) Project and NASA Airspace Systems Program's proposed initiative for the Transformation of the NAS (TNAS). The MCNA draws on the findings of the technology assessment that NASA GRC and ITT Industries are performing for the joint FAA-Eurocontrol Future Communications Study (FCS). The FCS is expected to lead to common global decisions on the future technologies for A-G and A-A voice and data communications in all domains of flight for the time frame from 2015 through 2030.

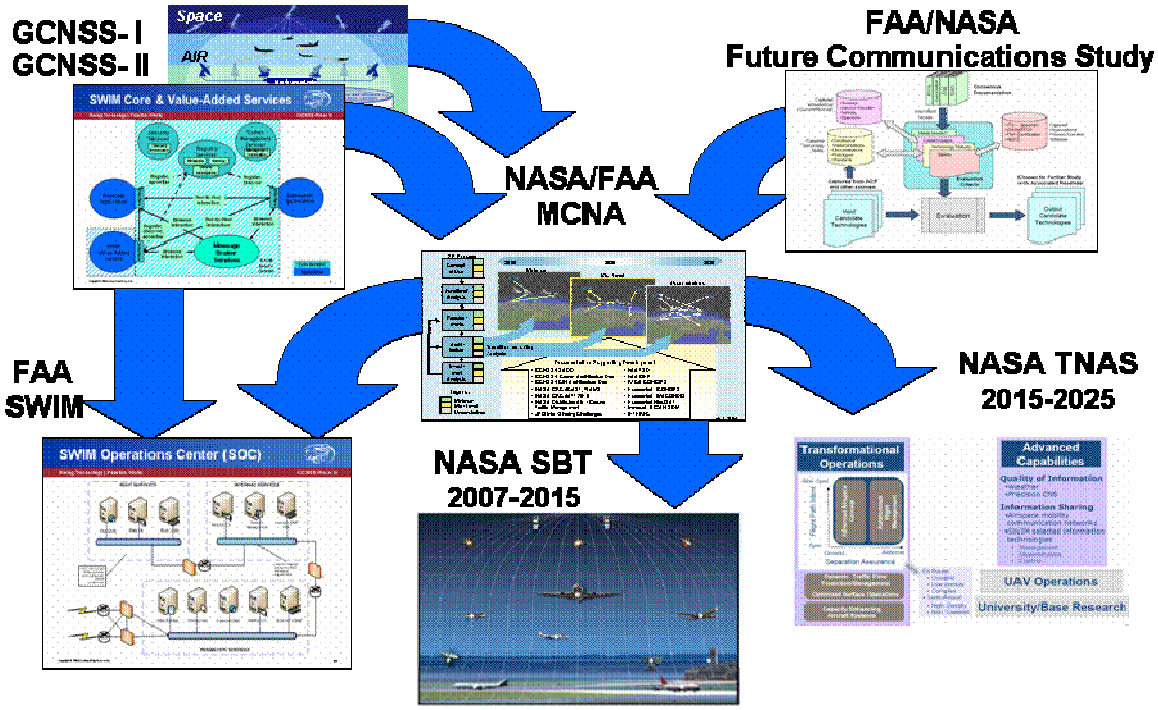

Figure 1: Flow of Information and Program Guidance Into and Out of MCNA.

1.2 Task Results Summary

As a mobile extension of SWIM, the MCNA provides structured mechanisms to extend the applications and benefits of SWIM to include all mobile elements of the NAS. While initial deployment of SWIM terrestrial infrastructure will not include safety critical ATS and AOC data, the MCNA already does. By providing A-G and A-A data communications for safety critical services, regularity of flight communications and tailored delivery of advisory information and user-specific situational information, the MCNA significantly expands SWIM's ability to perform network centric operations (NCO). These NCO provide for reduced aircraft spacing in all domains under normal conditions, and rapid, efficient responses to disruptions in the NAS due to severe weather and any other special situations. A broadly deployed MCNA enables mobile users anywhere in the NAS to have timely, reliable, secure access to the information needed for efficient collaborative decision making, optimized routes for reduced fuel consumption and emissions, and 4-D trajectory negotiation, continuous descent approaches and tailored arrivals in congested traffic of mixed aircraft, for increased airspace capacity in all flight domains. Finally, the MCNA vision to provide policy-based routing with priority and preemption across all data communications sub-networks with connections to the aircraft, and leverage both government and commercial communications assets enabled life-cycle cost savings.

2 INTRODUCTION

2.1 MCNA SE Process

While the MCNA task is not the first effort to evaluate current and future A-G and A-A NAS communications needs and capability, it is probably the first such effort based upon a SoSE approach. As such, the Boeing Team leveraged the results and conclusions from previous efforts. NexCom [4], AATT RTO-24 [1] and MACONDO [6], [7] are key examples of previous programs, studies and international plans that the Boeing Team leveraged in this effort. Furthermore, the Boeing Team worked to integrate MCNA planning with ongoing activities such as the Future Communication Study (FCS) whose goals and intentions closely overlap with MCNA in the nearer term timeframes.

The first step was to compile a comprehensive list of operational scenarios that are enabled by MCNA. Scenarios were selected that revolve around SWIM-enabled applications and information migrations that either require or are further enhanced by MCNA. Also, for completeness, additional scenarios, captured in previous external activities, were included in the MCNA scenario list.

The Boeing team conducted functional analysis from the perspective of the "vision" MCNA architecture to define the superset of functionality needed to support all possible present, near-future and envisioned operational scenarios. At the highest levels, most of the identified functions are necessary to deliver any communication service. However, exceptions were identified, highlighted and associated with the appropriate communication service class(es) and level(s). The construct of communication service classes with multiple service levels extends the concept of RCP. Defining communication classes with multiple levels of performance requirements, the communication service concept decouples the communication needs of operational scenarios from the performance capabilities of individual communication systems. Furthermore, multiple levels of service reduces infrastructure and operational and maintenance costs by preventing the most demanding operations from driving all aspects of the communication architecture.

The requirements analysis activity was one of the initial MCNA activities. Existing requirements bases were evaluated[1] to identify candidate requirements for MCNA. A key discrimination factor was to develop a set of MCNA system of systems (SoS) requirements that are independent of the individual voice and datalink systems that will compose MCNA. In this regard, the MCNA defines NAS communications as a network that integrates multiple networks and point-to-point links. Functional requirements were derived from the functional analysis. Performance requirements were identified for all defined service classes and levels. The values of the performance requirements are initial

[1] We started with the AATT RTO-24 requirements database, applying a disposition to these requirements and adding new requirements from other efforts and our work as appropriate.

starting points based on industry documents and must be refined and validated through detailed operational analysis. Characteristic and policy requirements were compiled from other requirements sources and derived, as necessary, from the functional analysis and performance requirements.

Another key aspect of the requirements effort was the development of a relational database that maps the operations scenarios to service classes/levels (Figure 2). The concept of service classes and levels is a pivotal construct of the MCNA SoSE requirements framework. The concept extends the notion of required communication performance (RCP) to define a set of communication service classes with similar functional, characteristic and relative performance requirements. Within each communication service class, one or more levels are defined to account for the various levels of criticality of the supported operations. This defined set of communication services/classes becomes the linchpin of the relational database that ties together performance requirements, operations scenarios and communication systems.

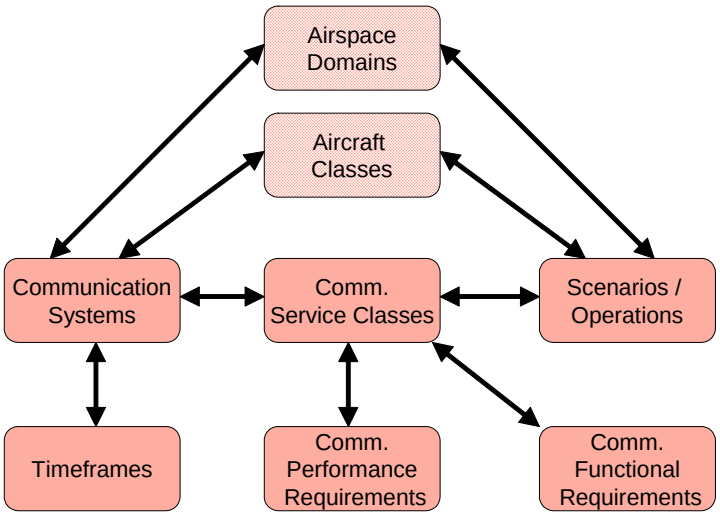

Figure 2: MCNA SoSE Relational Database.

The architecture activity evaluated the capabilities of existing and planned communication systems and mapped the defined communication services and levels to those systems. Also, proposed communications system architectures were defined that provide sufficient capability to deliver the identified services not provided by other systems. Finally, the architecture effort defined common networking protocols to integrate the various communication systems into an MCNA SoS and thereby provide any unaddressed functional capability.

The transition activity utilized the relational database to provide a temporal mapping of the deployment of systems, availability of communication services and correspondingly the timing for support of identified operational scenarios. The transition activity required a degree of interaction with the relational database to determine “target” dates for various architecture modifications and additions in order to align the transition plan with that for SWIM. Similarly, the feedback from high level investment analysis of

the MCNA deployment phases will likely result in the fine tuning of enhancement and system deployment timing as necessary to achieve a positive business case justification.

The MCNA investment analysis focused on identifying high value scenarios that will drive MCNA requirements and prioritizing the communications services. From these activities, a strategy roadmap was developed describing how MCNA communication links and protocols will evolve over time and identifying potential gaps in service in the 2015 timeframe. The investment analysis effort also identified and prioritized enabling technology research opportunities using the outputs and recommendations from the other tasks and surveying available literature for studies that have quantified the benefits of MCNA technologies. (See MCNA Investment Analysis Report, [13].)

In addition to the MCNA tasks described above, two adjunct activities were executed to provide more detailed development plans for technology maturation and simulation, emulation and demonstration capabilities. A Simulation, Emulation and Demonstration (SED) plan was developed to evaluate both needs and capabilities in this area and recommend targeted areas of development and activity that would provide maximum benefit. Also, a certification activity was undertaken to address at a high level the challenges; shortcoming and potential opportunities in the certification process as well as layout a longer term research and development plan to address system and service certification.

Building upon all of the other MCNA tasks, technology gaps were identified and a roadmap was created to highlight specific technology areas requiring additional focus and research investment. Furthermore, need dates were determined for the maturation of those identified technologies to enable the coordinated evolution of MCNA.

2.2 Document Roadmap

This section, ***Section 2***, provides an overview of the overall MCNA effort.

Section 3 summarizes the MCNA requirements analysis effort.

Section 4 describes key aspects of the MCNA architecture including the candidate link, the network architecture and the avionics architecture.

Section 5 summarizes the MCNA transition and interoperability analysis.

Section 6 summarizes the results and recommendations from the Simulation, Emulation and Demonstration (SED) effort.

Section 7 summarizes the results and recommendations from the MCNA Certification Report.

Section *Error! Reference source not found.* summarizes the results and recommendations from the MCNA Investment Analysis Report.

Section 9 describes the MCNA Technology Gaps and Roadmap effort.

Appendices provide references a comprehensive list of acronyms.

3 MCNA Requirements Analysis

The MCNA requirements analysis effort focused on three key aspects of the Systems Engineering (SE) process: scenario analysis, functional analysis and requirements analysis. Highlights from these fundamental aspects of the SE process are summarized below while the full scope of the requirements analysis effort is documented in the CDRL A046 MCNA Requirements Report [6].

3.1 Scenario Analysis

This effort investigated operational scenarios that would be enhanced by MCNA, with the intent of creating a representative list of MCNA-enabled scenarios. Scenarios were extracted from: NAS 5.0 Operational Improvements (OI), AATT RTO-24, MACONDO, SWIM Investment Analysis (Information Migrations & SWIM enabled applications) and MCNA team brainstorming, generating an initial list of over 70 scenarios. The original list of scenarios was synthesized to eliminate redundant scenarios, non-scenarios and scenarios that would be better defined as supporting communication applications. The resultant scenario list included 36 scenarios.

These 36 scenarios were further evaluated to formulate a relative ranking. Initially, the risks and benefits of each of the scenarios were evaluated using a small team of Subject Matter Experts (SME) in the field of operational analysis. These evaluations were then combined mathematically to rank the scenarios. In order to assure that the down-selection was robust to specific formulation of a representative mathematical equation, the risks and benefits were combined using several different methodologies. The down-selection of a given scenario was based upon either consistent performance across the all evaluation techniques or exemplary performance in one or more methods. Two considerations were used in the formulation of the different cost/benefit metrics:

- the mathematical techniques for combining the individual risk and benefit assessment
    - averaging
    - exponential
    - maximum
- the application of a weighting factor to account for which airspaces the scenarios would apply

The scenario down-selection process identified eight (8) scenarios that stood out as primary scenarios based upon overall benefit and risk performance (Table 1), four (4) secondary scenarios that are worthy of further analysis but did not perform as well as the primary scenarios (Table 2), and five scenarios that would incur higher risk but consequently yield much higher reward (Table 3).

Table 1: Primary Scenarios.

Scenario Number	Scenario	Description	Communication Services											Airspace Domain							Aircraft Class						Information Classes				Benefits					Risk (1-Lowest)				Source
			Party-line Voice	SA Voice	Broadcast Voice	Data Messaging	Trajecotry exchange	Broadcast to Aircraft	Broadcast From Aircraft	Ground to Air Data	Air to Ground Data	Air to Air Data	Video Exchange	Vehicle Command and Control	Gate	Surface	Terminal	En-route	Remote	Oceanic	Polar	Transport	Cargo	Military	UAV	GA - Business	GA - Personal	Surveillance	Weather	AIM	Flight Objects	Airspace Capacity (5 is highest)	Airport Capacity (5 is highest)	Efficiency (5 is highest)	Safety (5 is highest)	Security (5 is highest)	Non-Technical	Technical	Ground Implementation	Airline Implementation	
1	Deploy FIS-B Nationally	Free access nationwide for basic weather and NAS status information to equipped aircraft						3							Y	Y	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	N	Y	Y	N			4	2		1	1	1	2	OI - 103104
5	Autonomous Hazard Weather Alert Notification	Enhanced situations awareness via immediate simultaneous dissemination of hazardous weather to service providers, aircraft and airlines. **These products shall include microburst, turbulence and windshear warning in terminal airspace and shall be provided both automatically or upon pilot request.**			2	2		2		2					Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N				5		1	1	1	1	OI - 103117
10	Datalink to reduce routine workload	Expanded use of datalink for routine service provide activities to reduce workload.	2			2									Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	N	N	Y	3		2	1		1	1	1	1	OI - 102114
15	Enhanced Emergency Alerting	Using GPS position and aircraft ID, locate distressed or downed aircraft through ADS-B							1						N	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	N				4		1	1	1	1	OI - 106202
20	Optimize Runway Assignments	Improve sequencing and spacing of arriving aircraft with tools for better management of runway assignment. Tool provide and deliver pilot instructions and wake vortex warnings. Also provides hooks for a path from runway to en-route to improve flow.					2			2					N	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	N	N	Y	Y	2	3	2			2	1	2	1	OI - 104114
25	Controller awareness of ACAS resolutions	The system shall support the delivery and display to controllers of any resolution advisories generated by aircraft ACAS systems.				1									N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N				4		1	1	1	1	RTO-24
29	Aircraft push of security video and aircraft performance during emergency	For the purposes of security, it may be valuable to have mechanisms to trigger the downlink of streaming video and audio of the cockpit and cabin environments and send down critical aircraft performance data.							2		2		2		Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	Y	N	N	Y				1	4	3	1	1	3	NA (similar to GCNSS Demo Segment A)
32	Push of Security advisories to aircraft	When an airspace emergency occurs, it would be desirable to quickly distribute notification to affected aircraft, AOC/FOC, ARTCC and other government agencies				2									Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N				1	3	2	1	1	1	NA (new)

Table 2: Secondary Scenarios.

Scenario Number	Scenario	Description	Communication Services											Airspace Domain							Aircraft Class						Information Classes				Benefits					Risk (1-Lowest)				Source
			Party-line Voice	SA Voice	Broadcast Voice	Data Messaging	Trjaecotry exchange	Broadcast to Aircraft	Broadcast From Aircraft	Ground to Air Data	Air to Ground Data	Air to Air Data	Video Exchange	Vehicle Command and Control	Gate	Surface	Terminal	En-route	Remote	Oceanic	Polar	Transport	Cargo	Military	UAV	GA - Business	GA - Personal	Surveillance	Weather	AIM	Flight Objects	Airspace Capacity (5 is highest)	Airport Capacity (5 is highest)	Efficiency (5 is highest)	Safety (5 is highest)	Security (5 is highest)	Non-Technical	Technical	Ground Implementation	Airline Implementation	
16	Enhance Flight Data Management	FDP incorporates flight data info from flight deck into trajectory and conformance modeling. All plans treated as trajectories with protected volumes. Flight profiles can be negotiated and changes with strategic planners.					2								Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	Y	3				3	1	2	2	2	OI - 101202
17	Interactive Flight Planning From Anywhere	Interactive feedback of proposed flight plans based upon all current constraints. Provide near real time flight plan negotiation and changes.					2								Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	1		3			2	2	2	1	OI - 101103
18	Oceanic Separation to RNP-4	Oceanic separation is reduce to 30nmi lateral and 30nmi longitudinal based upon GPS based navigation, ADS surveillance and satellite communications (ADS & CPDLC)	3				2				2				N	N	N	N	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	3		3	1		1	1	1	1	OI - 107102
22	Flow Planning with distributed Schedule Recovery and Post Departure Rerouting	Distributed airline schedule recovery automation for utilizing combinations of ground delay, flight cancellation, and pre and post-departure re-routing to replan schedules in the face of convective weather disruptions. Take advantage of SWIM-enabled weather information distribution, improved forecasting, flight object, standardized route databases, and centralized allocation of forecast airport and airspace capacities					2								N	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	N	N	N	Y	2		4			2	2	2	1	SEA

Table 3: High Risk Scenarios[2].

Scenario Number	Scenario	Description	Communication Services												Airspace Domain							Aircraft Class						Information Classes				Benefits						Risk (1-Lowest)				Source
			Party-line Voice	SA Voice	Broadcast Voice	Data Messaging	Trjaecotry exchange	Broadcast to Aircraft	Broadcast From Aircraft	Ground to Air Data	Air to Ground Data	Air to Air Data	Video Exchange	Vehicle Command and Control	Gate	Surface	Terminal	En-route	Remote	Oceanic	Polar	Transport	Cargo	Military	UAV	GA - Business	GA - Personal	Surveillance	Weather	AIM	Flight Objects	Airspace Capacity (5 is highest)	Airport Capacity (5 is highest)	Efficiency (5 is highest)	Safety (5 is highest)	Security (5 is highest)	Non-Technical	Technical	Ground Implementation	Airline Implementation	
9	Shared Responsibility for Horizontal Separation	Delegate separation responsibility to pilots when it is operationally beneficial to do so.	2						1			1			N	N	N	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	N	N	3		1			3	3	1	3	OI - 102118
13	Improved Surface Separation Assurance	Pilots are provided high definition surface target information such as position, identification, velocity and infrastructure location (runways, taxiways etc.). On board automation systems display and advise the flight crew on surface movements and potential conflicts.	2			1			1	2					Y	Y	N	N	N	N	N	Y	Y	N	Y	Y	N	Y	N	Y	Y		2		4		2	2	1	3	OI - 102408
30	ROA Control	Ground control of an unpiloted aircraft												1	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	N	N	Y	Y	N	N						4	4	4	4	NA (new)
31	UAV Control	Autonomous control of an unpiloted aircraft with ground management					1	2	1	2	2				N	Y	Y	Y	Y	Y	Y	N	N	N	Y	N	N	Y	Y	Y	Y						4	4	4	4	NA (new)
36	Dynamic Resectorization	Provides tools to allow for more defintion of aispace configuration changes with automated functions to evaluate and develop asset assignments. Supports system to system coordination (SYSCO) of the reassignments across facility boundaries.	2			1	2	1	1						N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y										OI - 108207

[2] The benefits and risks of some of these scenarios still need to be analyzed. This effort will require the definition of new benefit classes beyond those originally define.

3.2 Functional Analysis

The MCNA functional analysis leverages heavily from the SWIM Functional Analysis Document, refined during the GCNSS II contract phase. At the highest level, two primary MCNA functions were defined: Provide Data Transport and Manage Data Transport (Figure 3). Provide data transport is further divided into five (5) Level-2 functions and subsequently each of these Layer-2 functions is further sub-divided into it's component Level-3 functions. For the MCNA effort, the majority of the functional analysis effort involved the functions within the Provide Data Transport Level-1 function. The other Level-1 function, Manage Data Transport, is very similar to the equivalent function within the SWIM functional analysis and generally follows the FCAPS model for network management.

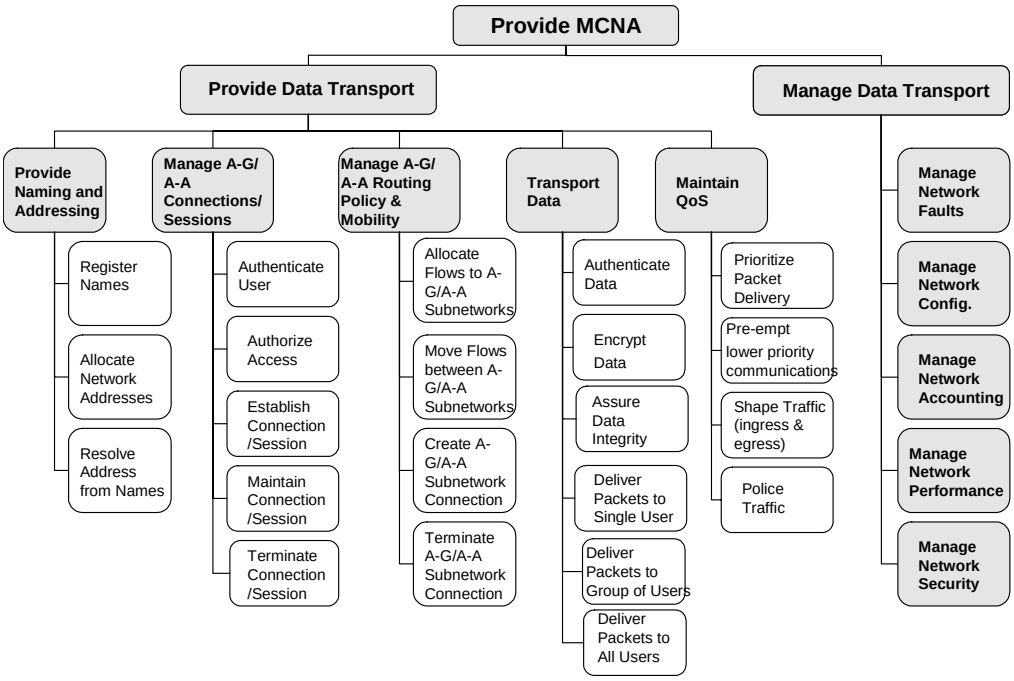

Figure 3: MCNA Functional Architecture.

3.3 MCNA Requirements

The current set of candidate MCNA system requirements leverages heavily from the functional analysis described above and from requirements extracted from industry documents. These requirements were categorized into functional, characteristic, policy, operational, service, security, transition, and performance requirements. This processes produced eighty five (85) MCNA system requirements (all requirements except for performance). A high level definition of these MCNA requirement categories is provided below in Table 4.

Table 4: MCNA System Requirement Categories.

Requirement Type	Description	Number
Functional	Requirements related to the functions provided by MCNA.	40
Characteristic	Requirements related to the characteristics of MCNA.	14
Policy	Requirements that are related to FAA/ATM policy.	13
Operational	Requirements that govern the use of the MCNA.	5
Security	Requirements related to the protection of data being communicated from malicious attack or being divulged to unknown/unauthorized parties.	7
Service	Requirements that capture the nature of the services that MCNA is required to provide.	4
Transition	Requirements imposed to assure seamlessly inter-operation during transition from exiting infrastructure to new infrastructure.	3

The MCNA performance requirements define the MCNA service classes and service levels. Table 5 contains the performance requirements of the three (3) different voice service classes. The tables summarize the performance targets for the mean latency, call establishment time, availability, integrity, and security requirements of each service level of the three different voice services classes.

The sources of the values in the table are a compendium of industry documents such as MACONDO and the FCS ICOCR and are not based on any operational analysis. The relatively relaxed integrity requirements of 1e-3 BER is based upon VOCODER technology that can provide MOS scores of 3.5 and above at these BER.

Table 5: Voice Services Performance Requirements.

Service Class	Service Level	Mean Latency	Call Establishment Time	Availability	Continuity	Integrity (BER)	Security
Party Line Voice	1	350ms	150ms	0.993	0.998	1.00E-03	NA
	2	350ms	150ms	0.993	0.998	1.00E-03	Authentication
	3	350ms	150ms	0.993	0.998	1.00E-03	Authentication
	4	350ms	20s	0.993	0.995	1.00E-03	Authentication
Selective Addressed Voice	1	350ms	5s	0.993	0.998	1.00E-03	Authentication
	2	485ms	20s	0.993	0.995	1.00E-03	Authentication
	3	485ms	40s	0.993	0.95	1.00E-03	Authentication
Broadcast Voice	1	485ms	NA	0.99999	0.998	1.00E-03	NA
	2	485ms	NA	0.99	0.995	1.00E-03	NA

Table 6 contains the performance requirements of the MCNA data service classes and levels. These are the performance requirements for the nine (9) different data service classes. The primary source of the values in the table, with a few exceptions, was the MACONDO study, [6]. Other sources include the Performance-based operations Aviations Rulemaking Committee (PARC) RCP effort [3].

Table 6: Data Services Performance Requirements.

Service Class	Service Level	95% Message Latency* (secs)	Expiration Time (secs)	Availability	Continuity	Integrity (Undetected PLR)	Security
Data Messaging	1	2	20	0.9995	0.995	1.00E-05	Authentication, Confidentiality
	2	5	40	0.9995	0.995	1.00E-05	Authentication
	3	10	60	0.9995	0.995	1.00E-05	Authentication
	4	30	120	0.9995	0.995	1.00E-05	Authentication
Trajectory Exchange	1	30	120	0.9995	0.995	1.00E-08	Authentication, Confidentiality
	2	30	120	0.9995	0.995	1.00E-08	Authentication, Confidentiality
Broadcast to Aircraft	1	3	5	0.9995	0.995	1.00E-05	Authentication
	2	5	15	0.999	0.99	1.00E-05	Authentication
	3	30	60	0.999	0.99	1.00E-05	Authentication
Broadcast from Aircraft	1	3	5	0.999	0.99	1.00E-05	N/A
	2	5	15	0.999	0.99	1.00E-05	N/A
	3	10	20	0.999	0.99	1.00E-05	N/A
Ground to Air Data	1	5	40	0.999	0.99	1.00E-05	Authentication
	2	10	60	0.999	0.99	1.00E-05	Authentication
	3	30	120	0.999	0.99	1.00E-05	Authentication
Air to Ground Data	1	5	40	0.999	0.99	1.00E-05	Authentication
	2	10	60	0.999	0.99	1.00E-05	Authentication
	3	30	120	0.999	0.99	1.00E-05	Authentication
Air to Air Data	1	3	20	0.999	0.99	1.00E-05	N/A
	2	5	40	0.9995	0.995	1.00E-05	N/A
	3	30	120	0.9995	0.995	1.00E-05	N/A
Video Exchange	1	1	2	0.99999	0.999	1.00E-05	Authentication, Confidentiality
	2	5	40	0.999	0.99	1.00E-05	Authentication, Confidentiality
Command & Control	1	1	2	0.999999	1	1.00E-08	Authentication, Confidentiality
	2	1	2	0.99999	0.999	1.00E-08	Authentication, Confidentiality
	3	1	2	0.9999	0.99	1.00E-08	Authentication, Confidentiality

4 MCNA Architecture

The MCNA architecture definition effort focused on three key aspects of the MCNA Architecture: candidate links, the network architecture and the avionics architecture. Highlights from these key architectural perspectives are summarized below while the full detail of the MCNA architecture definition task is documented in the CDRL A040 MCNA Architecture Report [7].

4.1 Candidate Links

The candidate links represent an aggregate of disparate wireless communications systems that can be used to inter-connect aircraft and ground automations systems. A physical architecture diagram representing the candidate links under consideration for MCNA is shown in Figure 4. A key aspect of the physical architecture is the fact that multiple disparate networking protocols are currently in use with the number increasing before eventually converging toward a smaller set of standard network protocols.

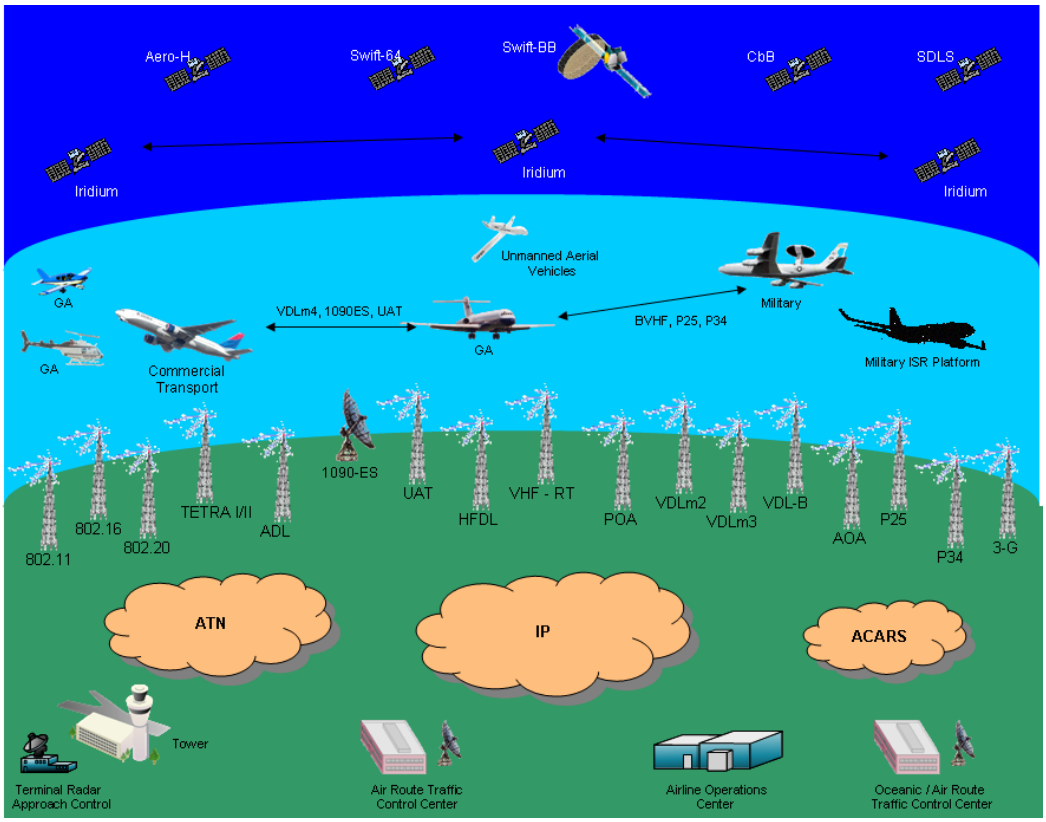

Figure 4: MCNA System of Systems View.

Table 7 summarizes information about each of the candidate air-ground links, grouped into categories Air-Ground communications, Satellite communications, Air-Air

Communications, and Airport Communications. Most of the candidates were extracted from the initial findings and recommendations in the technology pre-screening assessment of the Future Communications Study (FCS), conducted for NASA by ITT Industries. However, additional links were also included, mostly to account for existing systems that were not described in the aforementioned study. The MCNA link assessment also brought into focus the intended candidate link networking protocol(s) as a key evaluation factor in selecting future A-G links.

Table 7: MCNA Candidate Links Evaluation Table.

General Characteristics						Communication Services												Airspace Domain						Aircraft Class						Risk (1-3)				Cost (0- 6)				Link Type		
Candidate Link Type	Link ID Number	Associated Networking Protocols	Spectrum	SWIM Support (3 is highest)	Availability (date)	Party-line Voice	SA Voice	Broadcast Voice	Data Messaging	Trajectory exchange	Broadcast to Aircraft	Broadcast From Aircraft	Ground to Air Data	Air to Ground Data	Air to Air Data	Video Exchange	Comm. and Control	Gate	Surface	Terminal	En-route	Remote	Oceanic	Polar	Transport	Cargo	Military	UAV/ROA	GA - Business	GA - Personal	TRL	Standardization	Certifiability	Political	System	Maintenance	Service	Avionics	A-G	A-A	A-S
Air-Ground Communications																																								
VHF Analog Voice	1	NA	VHF	0	2005	1		1										Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	1	1	1	1	0	4	0	1	Y	Y	N
HF Analog Voice	2	NA	HF	0	2005		3											N	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	1	1	1	1	0	2	0	3.5	Y	Y	N
Plain old ACARS (POA)	3	ACARS	VHF	1	2005				3									Y	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	1	1	1	1	0	0	3	2	Y	N	N
VDLm2	4	ACARS	VHF	1	2005				3				3	3				Y	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	1	1	1	1	0	0	2.5	2.5	Y	N	N
	5	CLNP	VHF	2	2010			2	2	2			3	3											Y	Y	N	N	Y	N	1	1	1	2	0	0	2.5	2.5			
	6	IP	VHF	2	2010			2	3		3	3	3	3											Y	Y	N	N	Y	N	2	3	3	2	0	0	2.5	2.5			
	7	NA (VDL-B)	VHF	2	2005						2														Y	Y	Y	Y	Y	Y	1	1	1	1	2	2	0	2			
VDLm3	8	CLNP	VHF, DME	2	2020				1	1							2	Y	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	1	1	1	3	4	3	0	2.5	Y	N	N
	9	Voice		1	2015	1		1																															Y	Y	N
HFDL	10	ACARS	HF	1	2005				3									N	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	1	1	1	1	0	0	3.5	3.5	Y	N	N
	11	CLNP			2010																																				
3G	12	IP	DME	3	2020	3	2	1	1	1	1	1	1	1		2	2	Y	Y	Y	Y	N	N	N	Y	Y	N	N	Y	Y	2	3	3	2	3	3	0	3	Y	N	N
Satellite Communications																																								
Aero-H	13	ACARS (data-2)	AMSRS	1	2005																										1	1	1	1							
	14	CLNP (data-3)			201U		2		2	2								Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	2	2	2	1	0	0	5	4.5	N	N	Y
	15	IP (data-3)			2010																										2	2	2	2							
Swift-64	16	IP	AMSRS	1	2005		3	1	3		3	3	3	3			3	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	1	3	3	2	0	0	3	4	N	N	Y
Swift-Broadband	17	IP	AMSRS	3	2010	3	2	1	1	1	2	3	1	1		2	2	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	2	2	2	2	0	0	2	4	N	N	Y
SDARS	18	IP	S-Band	2	2015			1			2							Y	Y	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	2	3	3	2	0	2	0	1.5	N	N	Y
SDLS	19	NA	AMSRS	2	2015	3	1	1	1	1	2	3	1	1				Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	3	3	3	3	2	3	0	3	N	N	Y
Iridium	20	Layer-2	L-Band	1	2005		3		3		3							Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	1	2	3	3	0	0	2.5	2	N	N	Y
Connexion by Boeing	21	IP	FSS	3	2005	4	3	2	3		3	3	3	3		2	3	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	1	3	3	3	0	0	2	6	N	N	Y
Air-Air Communications																																								
1090-ES	22	CLNP	DME	1	2010				2	2					1			N	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	N	1	1	1	1	1	1	0	2	Y	Y	N
	23	Layer-2	DME	1	2005						1	1						Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N											
UAT	24	Layer-2	DME	2	2010						1	1						N	Y	Y	Y	Y	N	N	N	N	N	N	Y	Y	1	1	2	2	3	3	0	3	Y	Y	N
VDLm4	25	CLNP	VHF	1	2010							1			1			N	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	1	1	2	3	0	0	0	3	N	Y	N
B-VHF	26	CLNP	VHF, DME	3	2025	1	1	1	1	1			1	1	1		2	Y	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	3	3	3	2	4.5	3	0	3	Y	Y	N
	27	IP				1	1	1	1	1	1		1	1	1		2																								
P-25	28	IP	DME	1	2020	1	1	1	3									Y	Y	Y	N	N	N	N	Y	Y	Y	N	Y	Y	2	3	3	2	4	3	0	3	Y	Y	N
P-34	29	IP	DME, MLS	3	2025	2	2	1	1	1	1	1	1	1	2	2	2	Y	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	2	3	3	2	5	4	0	3	Y	Y	N
Airport Communications																																								
Airport Data Link (ADL)	30	NA	MLS	3	2025	2	1	1	1	1	1	3	1	1		1	1	Y	Y	N	N	N	N	N	Y	Y	N	N	Y	Y	3	3	3	2	2	2	0	3	Y	N	N
IEEE 802.11	31	IP	ISM	3	2010			2	3		3		3	3				Y	N	N	N	N	N	N	Y	Y	N	N	Y	Y	1	2	3	2	1.5	1.5	0	2	Y	N	N
	32	CLNP			2015			2	3				3	3																											
IEEE 802.16	33	IP	ISM, MLS	3	2020	2	1	1	1	1	1	1	1	1	1	1	1	Y	Y	N	N	N	N	N	Y	Y	N	N	Y	Y	1	3	3	2	2	2	0	3	Y	N	N
	34	CLNP				2	1	1	1	1			1	1	1	1	1																								
IEEE 802.20	35	IP	ISM, DME	3	2025	2	2	1	1	1	2	2	1	1		2	2	Y	Y	N	N	N	N	N	Y	Y	N	N	Y	Y	2	3	3	2	2	2	0	3	Y	N	N
	36	CLNP				2	1	1	1	1		2	1	1		2	2																								
TETRA I/II	37	IP	DME	2	2025	1	1	1	1	1	1	1					1	Y	Y	N	N	N	N	N	Y	Y	N	N	Y	Y	2	3	3	2	2	2	0	3	Y	N	N

4.2 Network Architecture

A key aspect of the aviation communications environment that greatly complicates the MCNA network architecture is the simultaneous existence of three networking protocols: ACARS, ATN/CLNP and IP. ACARS is currently the most prevalent for ATS datalink but plans are currently being implemented to supplant ACARS with ATN. Furthermore, the industry generally acknowledges that, in the end state, network communications will transition to IP. IP is particularly desirable for support of Aeronautical Passenger Communication (APC) and Aeronautical Administrative Communications (AAC) services with more recent interest in the benefits of using IP for Aeronautical Operations Communication (AOC) services. Historically, the business case for datalink has been justified through the ancillary uses of common avionics. For example, AOC accounts for approximately 90% of ACARS traffic. For this reason, the migration of all aeronautical communications to IP becomes a desirable end vision.

The MCNA Architecture (Figure 5) acknowledges the current existence of ACARS and ATN/CLNP but strives to enable a transition towards IP-based A-G communications. The current IP protocols lack certain functionality, such as mobility that supports multihoming and Policy-Based Routing (PBR), which was specifically designed into the ATN protocols. While efforts are underway to develop protocols extensions to IPv6 that enable mobility with multihoming and PBR support, the MCNA Architecture addresses nearer term deployment of IP services using SWIM messaging.

Like ACARS, the SWIM messaging service is an application layer (Layer 7) message addressing and routing capability. Since much of the current and near future ATS A-G communication needs are messaging based, this architectural solution allows the near term adoption of IP links for limited ATS & AOC and full AAC & APC communication services with a future migration path upon completion of the IPv6 protocol extensions. The use of SWIM messaging has further advantages in that it provides a means of interworking between ACARS, ATN/CLNP and IP and it accelerates the goal of extending SWIM services to the aircraft.

Another useful feature of this architecture is that the use of a Message Transport Service (MTS) to transport SWIM information eliminates the need for network layer mobility with support for multihoming and policy based routing. Since message routers exhibit store & forward behavior, mobility can be achieved by rapid reconnection with the message router following link loss or handover. Message routers exchange information at the application layer. This provides for custom implementations of these message routers to achieve policy-based routing and multihoming objectives.

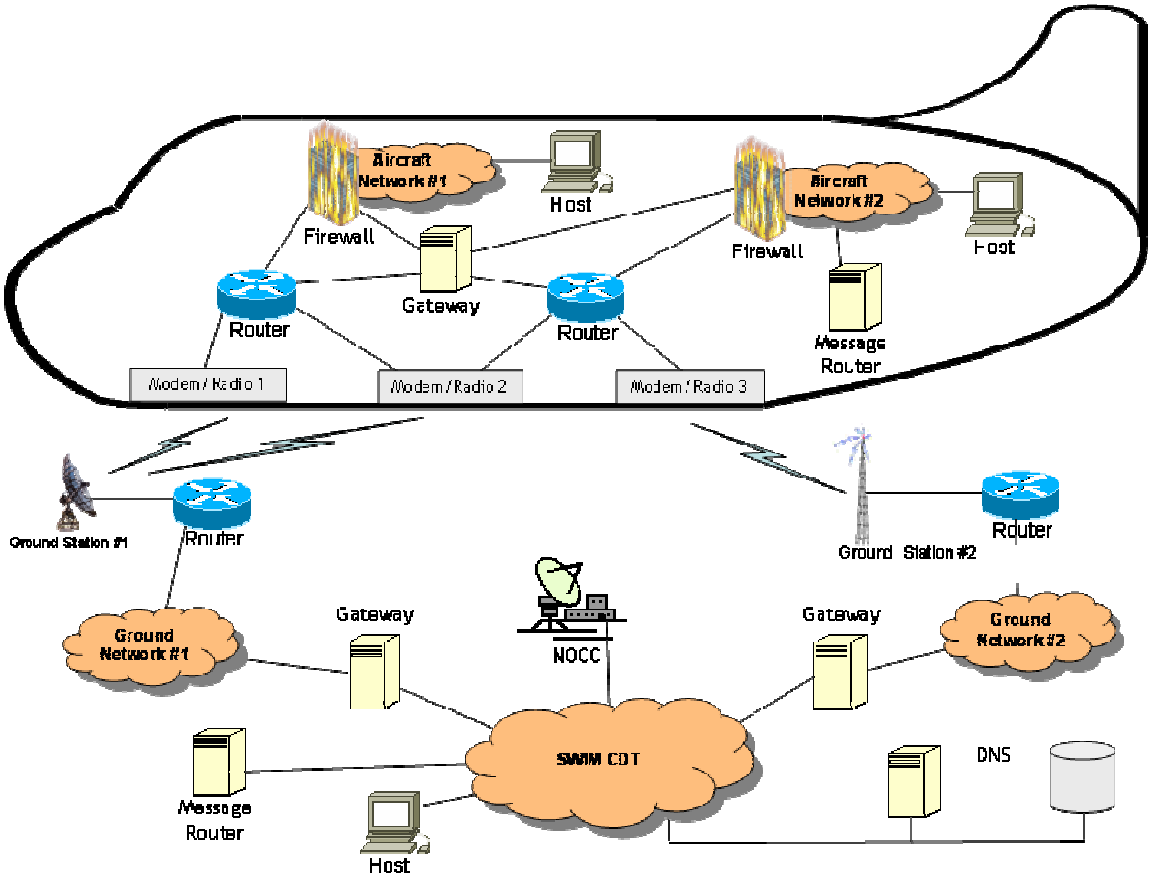

Figure 5: MCNA Architecture.

4.3 MCNA & SWIM

Three implementation options, Initial, Transition & Vision, have been defined for the extension of SWIM to the aircraft via MCNA (Figure 6). These options outline a progression of MCNA deployment, however, it should be noted that at a given time, an aircraft might implement multiple options simultaneously in support of various applications. The initial and simplest implementation option limits the scope of SWIM to the ground. A legacy aircraft application would use existing air-ground communications to exchange data with a SWIM Enabled Application (SEA). This SEA would provide the functions of a terrestrial SWIM Adapter providing a mechanism for non-SEA to publish and subscribe to SWIM information.

The vision implementation assumes ubiquitous availability of IP-based A-G communications that support all of the required functions and capabilities necessary to extend the Common Data Transport (CDT) to the aircraft. Aircraft applications are either developed natively as SEA or interface with the SWIM via an airborne Adapter. The key difference between this architecture and the terrestrial SWIM interaction model is the inclusion of an additional SWIM Shared Services (S3) element for caching and local

distribution of SWIM services. While not a required architectural component, it is anticipated that the bandwidth restriction inherent in A-G communications will mandate the need to provide a subset of SWIM services local to the aircraft domain.

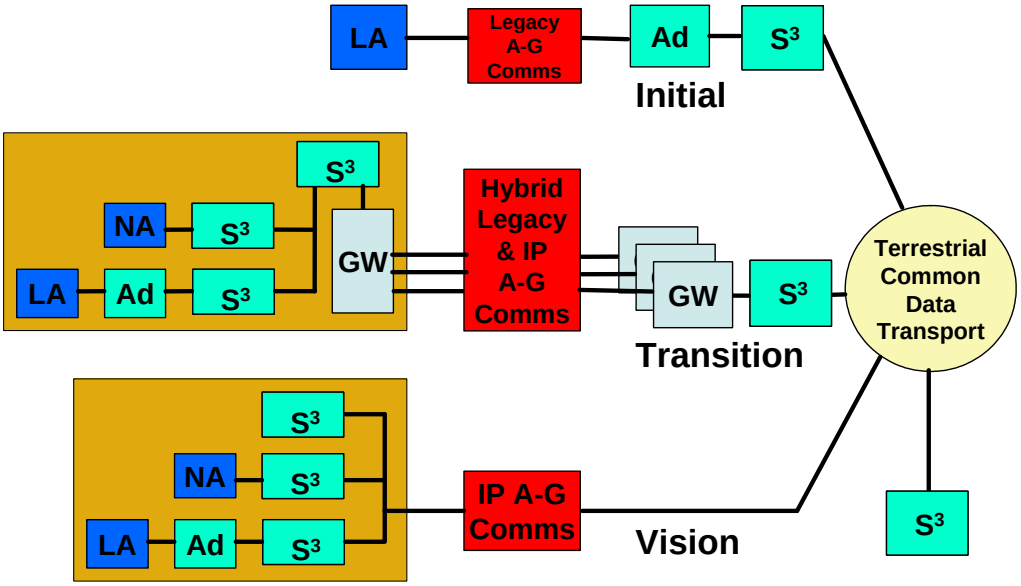

Figure 6: Extending SWIM to the Aircraft with MCNA.

The transitional implementation solution is the most complex and involves a range of implementation options that will likely be employed during the anticipated extended transition period. In these options, ubiquitous A-G IP-based connectivity is not available. Instead, an aggregate of links supporting ACARS, ATN and IP are available. Since many of these links are not capable of supporting the extension of the CDT to the aircraft, SWIM message routing is employed to extend a subset of SWIM services to the aircraft. A SWIM compliant message router is placed on the aircraft as part of the S3. As with the vision implementation, native applications interface with SWIM directly through this SWIM message routers while legacy applications require an adaptor. The airborne message routers can communicate with terrestrial SWIM message routers over a variety of candidate links. Message gateways are employed on both the aircraft and ground to transport/transform messages between routers over these disparate candidate links.

4.4 Avionics Architecture

While the network-centric SWIM environment is intended to transform operation of the NAS, operational and air traffic efficiency are further enhanced when IP-based SWIM services are available to each aircraft. Recently, commercial networks supporting Internet Protocols are increasingly being installed on aircraft for both on and off-board communications although operational and air-traffic services are still using dedicated, legacy air/ground networks (e.g., VDL, ACARS). Therefore, it is essential to modernize

the avionics architecture to seamlessly and cost-effectively extend the SWIM services to aircraft by leveraging the IP-based commercial networks while assuring the safety of flight.

Traditional aircraft communication systems use the federated architecture, which consists of dedicated hardware devices. Since dedicated devices tend to drive up the cost of operation & maintenance (O&M), newer avionics architectures include integration among sub-systems based on software-defined functions over a limited number of common hardware platforms. Integrated systems can lower costs, enhance resource allocation, and improve system availability. This trend is true across markets from air transport to general aviation. The availability of commercial datalink systems and software-defined integrated avionics are important steps toward realizing an avionic architecture that can support network-centric ATM as well as comply with existing ICAO FANS concept.

As illustrated in Figure 7, the proposed vision-state architecture is based on the AEEC Aircraft Data Networks (ADN) domain model. It groups on-board functions and services into three domains according to their criticality and performance requirements. Communication within and across domain boundaries are provided by IP-based networks. The vision state architecture selects IPv6 as the end-state communication protocol to achieve interoperability, scalability, cost-effectiveness, and manageability. Security measures, such as firewalls and cryptographic schemes, are proposed to protect domains from unauthorized access. Regulatory and certification requirements will continue to confine tactical ATC communications to ICAO-specified air/ground networks, such as VDL, HFDL, Mode-S and NGSS. These ATN-compliant subnetworks will exist in the vision state and will be dedicated to the aircraft control domain (ACD). All on and off board communications will be managed by a router function, located within the ACD, to ensure equitable resource sharing among applications of various criticality levels.

The AEEC has specified the use of file servers as repository of information for on-board applications. SWIM services will also require similar capabilities. Therefore, it is recommended that all SWIM functions be implemented in the Network File Server (NFS) and the Cabin File Server (CFS) serving the ACD and the Airline Information Services

Domain (AISD) respectively.

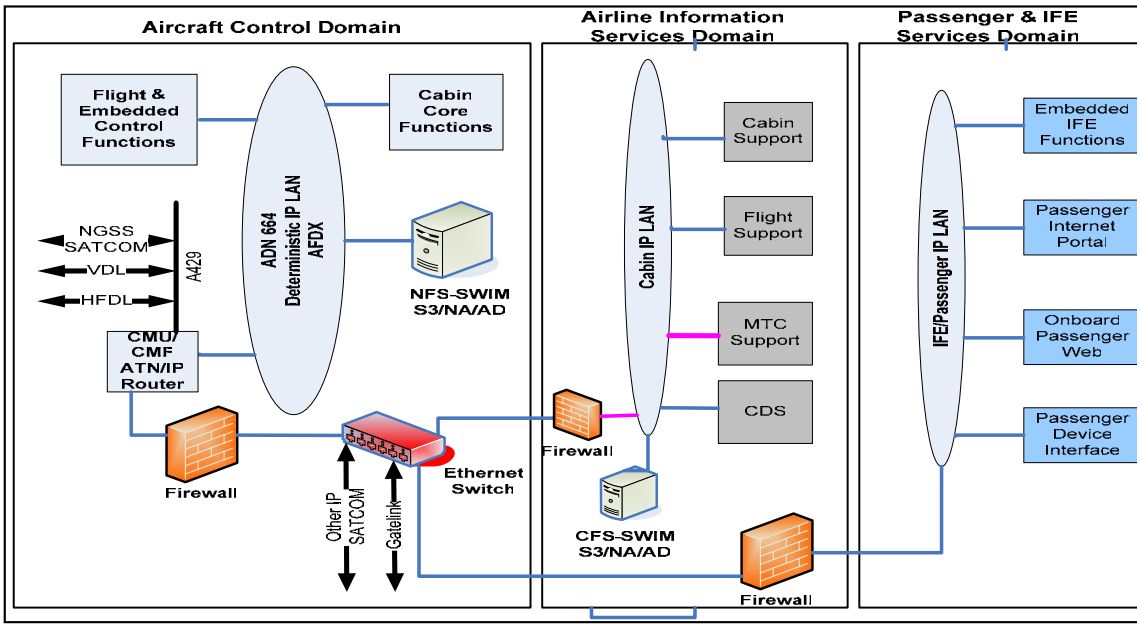

Figure 7: Vision State Architecture.

Migration to the vision state architecture should be an evolutionary process. A roadmap should be created to transform the avionics architecture from the current state to the vision state in incremental steps that optimizes the cost/benefit tradeoffs. Due to the interdependency of avionics and ground systems to achieve full benefits of SWIM, aircraft operators and terrestrial system providers must commit to the technology roadmap and perform lock-step transitions. However, the terrestrial systems must be fully backward compatible to accommodate aircrafts with different equipage levels and at different transition steps.

Several risks emerge from the use of commercial networks in the vision state architecture due to the limitations of Internet protocols. The foremost technical challenge is to develop mobility management, congestion control, global addressing and security/firewall rules that meets the aviation system needs. Some of these technology gaps can be mitigated by implementing IPv6 as a subnetwork to ATN. To use IP without the ATN networking capabilities, several aviation standards must be developed to address these limitations. Although AEEC has undertaken some of the IP specification activities, a top-down, coordinated effort is required at ICAO, RTCA and AEEC to develop a consistent set of specifications.

Current regulatory procedures are inadequate to certify the use of commercial networks for air traffic management. The certification process is further complicated by the integrated platforms and software defined functions. New capabilities may be added incrementally to keep pace with evolving commercial networks by changing a portion of the software. Therefore, a strategy needs to be developed to permit incremental

certification of systems, which is not possible under current certification process. Section 7 of this Final Report describes a system and service level approach to simply the certification process that would be necessary for the vision state avionics. The Required Communication Performance (RCP) concept being considered by RTCA would be ideal to qualify and approve commercial networks for air traffic operation. RCP will provide the flexibility and adaptability necessary to avoid the risk of obsolescence. Appropriate aviation standards should be updated to capture the service/system level certification approach and the RCP concept such that global interoperability and safety of life can be assured while increasing implementation flexibility and reducing certification costs.

5 MCNA Transition Analysis

The transition analysis conducted a high level investigation of concepts for the transition from today's disparate communication systems with uneven coverage and insufficient capabilities toward a single integrated Mobile Communication Network Architecture that will support System Wide Information Management (SWIM) and Network Centric Operations (NCO). The transition analysis was influenced by the MCNA operational scenario evaluation that was part of the requirements analysis and the candidate link evaluation that was part of the MCNA architecture subtask. The transition analysis incorporate the eight (8) primary scenarios that were chosen based on a favorable ratio of benefit to risk. The thirty-seven (37) candidate communication links considered in the transition analysis are a union of those considered in the Future Communication Study (FCS) and the set of links currently in use. Highlights from these key transitional subtasks are summarized below while the full detail of the MCNA transition and interoperability task is documented in the CDRL A042 MCNA Transitional and Interoperable Report [10].

5.1 Total Communication System Performance

Total Communication System Performance (TCSP) levels for each timeframe were defined and described in the MCNA Transition and Interoperability Report. The TCSP levels spans from currently available MCNA capabilities to the vision of the MCNA in the 2030 timeframe, Table 8. The TCSP levels were defined by allocating the communication services and corresponding service levels to four deployment spirals/time frames. The existence of a communication service class of a particular level in a timeframe was determined by examination of the communication links available at that time. This was tempered by the MCNA team's judgment on equipage rates and roll out of operational scenarios that would make use of those service classes.

In later MCNA deployment spirals, the need for communication services at specific levels in a airspace domain or for a aircraft class is not ubiquitous. For example, ADS broadcast is not applicable while an aircraft is at the gate. Thus, even in the vision time frame, the Broadcast From Aircraft (BFA) data communication service is not required. Table 8 reflects the four (4) TCSP levels. The entries are color coded to reflect the confidence of the MCNA team of the coverage of the communication service in the specific airspace domain or aircraft class. Green represents the most confidence, yellow indicates less confidence, and red represents the least confidence.

Table 8: MCNA Total Communication System Perofmrance.

			Airspace Domains							Aircraft Classes					
		Communication Service Class	Gate	Surface	Terminal	En Route	Remote	Oceanic	Polar	Transport	Cargo	Business Jet	GA	Military	UAV/ROA
2005	Voice	Party Line Voice	1	1	1	1	NA	NA	NA	1	1	1	1	1	NA
		Selective Addressed Voice	NA	NA	NA	2	2	2	NA	2	2	2	3	2	NA
		Broadcast Voice	1	1	1	1	NA	NA	NA	1	1	1	1	1	NA
	Data	Data Messaging	3	3	3	3	2	2	3	2	2	NA	NA	NA	NA
		Trajectory Exchange	NA	NA`	NA	NA	2	2	NA	2	2	NA	NA	NA	NA
		Broadcast to Aircraft	NA	3	3	3	NA	NA	NA	3	3	3	3	NA	NA
		Broadcast from Aircraft	NA	NA	NA	NA	NA	3	NA	3	3	NA	NA	NA	NA
		Ground to Air Data	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Air to Ground Data	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Air to Air Data	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Video Exchange	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Command and Control	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2005-2010	Voice	Party Line Voice	1	1	1	1	4	4	NA	1	1	1	1	1	3
		Selective Addressed Voice	2	2	2	2	2	2	3	2	2	2	NA	2	NA
		Broadcast Voice	1	1	1	1	1	1	NA	1	1	1	1	1	1
	Data	Data Messaging	2	2	2	1	1	1	3	1	1	1	NA	NA	NA
		Trajectory Exchange	2	2	2	1	1	1	NA	1	1	1	NA	NA	NA
		Broadcast to Aircraft	3	2	2	2	2	2	NA	2	2	2	3	NA	NA
		Broadcast from Aircraft	NA	3	3	3	3	3	3	3	3	3	NA	NA	3
		Ground to Air Data	3	3	3	3	3	3	NA	3	3	NA	NA	NA	NA
		Air to Ground Data	3	3	3	3	3	3	NA	3	3	NA	NA	NA	NA
		Air to Air Data	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Video Exchange	2	2	2	2	2	2	NA	2	2	NA	NA	NA	NA
		Command and Control	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA	NA	3
2010-2020	Voice	Party Line Voice	1	1	1	1	3	3	NA	1	1	1	1	1	2
		Selective Addressed Voice	1	1	1	1	2	2	3	1	1	1	NA	1	NA
		Broadcast Voice	1	1	1	1	1	1	NA	1	1	1	1	1	1
	Data	Data Messaging	1	1	1	1	1	1	3	1	1	1	NA	1	NA
		Trajectory Exchange	1	1	1	1	1	1	NA	1	1	1	NA	1	1
		Broadcast to Aircraft	3	2	2	2	2	2	NA	2	2	2	3	NA	NA
		Broadcast from Aircraft	NA	1	1	2	2	2	2	1	1	1	3	NA	2
		Ground to Air Data	2	2	2	2	2	2	NA	2	2	2	NA	NA	NA
		Air to Ground Data	2	2	2	2	2	2	NA	2	2	2	NA	NA	NA
		Air to Air Data	NA	NA	2	2	3	3	3	2	2	2	NA	NA	NA
		Video Exchange	2	2	2	1	1	1	NA	2	2	NA	NA	NA	1
		Command and Control	NA	NA	NA	2	3	3	NA	NA	NA	NA	NA	NA	2
2020-2030	Voice	Party Line Voice	1	1	1	1	1	1	NA	1	1	1	1	1	1
		Selective Addressed Voice	1	1	1	1	2	2	2	1	1	1	1	1	NA
		Broadcast Voice	1	1	1	1	1	1	NA	1	1	1	1	1	1
	Data	Data Messaging	1	1	1	1	1	1	2	1	1	1	1	1	NA
		Trajectory Exchange	2	2	1	1	1	1	2	1	1	1	1	1	1
		Broadcast to Aircraft	3	1	1	1	1	1	3	1	1	1	1	1	NA
		Broadcast from Aircraft	NA	1	1	2	2	2	2	1	1	1	1	1	1
		Ground to Air Data	2	1	1	1	1	1	NA	1	1	1	1	1	NA
		Air to Ground Data	2	1	1	1	1	1	NA	1	1	1	1	1	NA
		Air to Air Data	NA	NA	1	1	1	1	1	1	1	1	1	1	NA
		Video Exchange	2	1	1	1	1	1	NA	2	2	NA	NA	NA	1
		Command and Control	NA	1	1	1	3	3	3	NA	NA	NA	NA	NA	1

5.2 Representative Transition Paths

The transition analysis was conducted by correlating the required communication services requirements from the eight (8) primary MCNA scenarios with the candidate links that can provide those services. Figure 8, Figure 9, and Figure 10 show the

resulting representative transition path diagrams. The subset of communication links seen in these diagrams is based on selecting those that have the lowest risk and cost that provide the needed services to meet the needs of a scenario at the earliest possible time. The analysis indicates that it is possible to provide all of these operational scenarios before 2015.

Scenario #15 (Enhanced Emergency Alerting) only requires Broadcast from Aircraft Level 1 (BFA1) and can begin before 2010 using 1090ES (layer 2) for all aircraft classes except GA. In 2010, as UAT becomes available, this operation scenario coverage extends to include GA aircraft.

Scenario #25 (Controller awareness of TCAS resolutions) requires Data Messaging Level 1 which will first be available when SwiftBroadband arrives in the 2010 timeframe. Therefore, this scenario could be supported sometime before 2015.

Scenario #29 (Aircraft push of security video and aircraft performance during emergency) requires three different data communication services. While Broadcast from Aircraft Level 2 (BFA2) is possible in the near future, Video Exchange Level 2 (V2) and Air to Ground Data Level 2 (FD2) is not available until after 2010 via Swift Broadband, VDLm2 (CLNP), or 1090ES (CLNP). This could probably be pushed forward in time by using other satellite or terrestrial based communication services for V2 and using another service other than Air to Ground Level 2 (which implies SWIM).

Scenario #32 (Push of Security advisories to aircraft) only requires Data Messaging Level 2 (DM2) which is currently provided by Aero-H (ACARS over data 2). This provides coverage to properly equipped aircraft until 2010 when VDLm2 (CLNP), Swift Broadband, and 1090ES (CLNP) should be available to extend the coverage of DM2 to more aircraft.

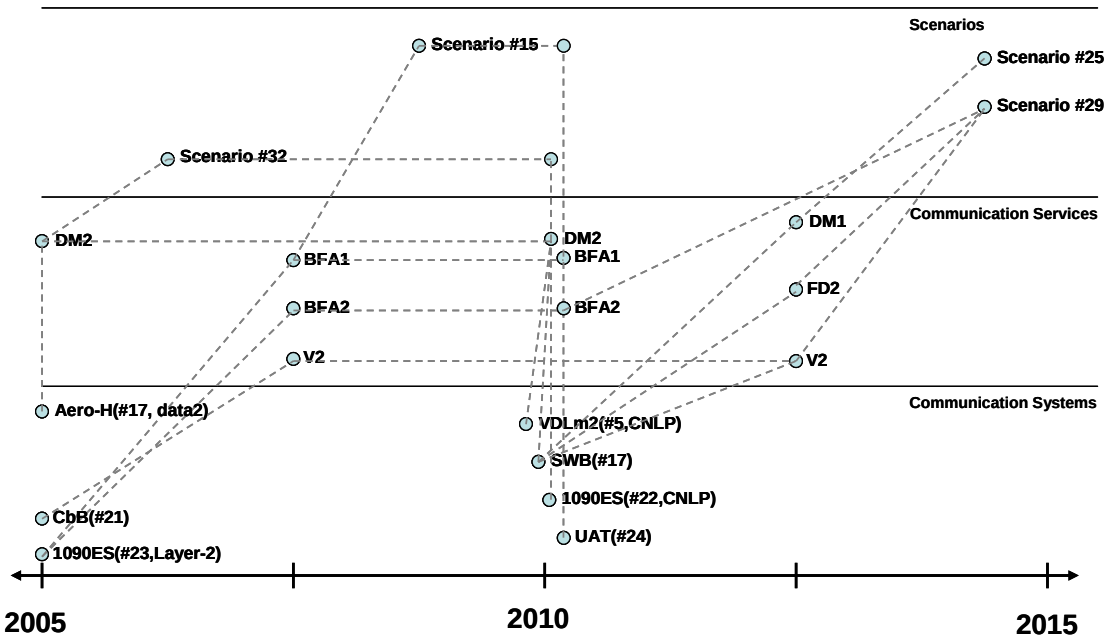

Figure 8: Safety and Security Operational Scenarios.

Scenario #1 (Deploy FIS-B Nationally) requires the least stringent Broadcast to Aircraft service level (BTA3). Initially, this can be provided by VDLm2 (VDL-B) and 1090ES (Layer 2). In the 2010 timeframe, this can be supplemented with Swift Broadband and UAT.

Scenario #10 (Datalink to reduce routine workload) requires the least stringent Data Messaging service level and party line voice service level 3 (DM3 & PLV3). In the near term, this can be provided through aircraft equipped with Aero-H for the data service and through current VHF analog voice service. Later, near 2010, this can be supplemented with VDLm2 (CLNP), Swift Broadband, and 1090ES (CLNP). These additional candidate links will extend the coverage to more aircraft; those equipped for any of these candidate links. In addition, the option of using any of these candidates links provide the potential of cost savings to the FAA and airlines through reduced equipage, service, and maintenance costs.

Scenario #20 (Optimize Runway Assignments) is deferred until after 2010 because it requires Trajectory Exchange 2 (TE2) and Air to Ground Data 2 (FU2) which are not available until VDLm2 (CLNP), SwiftBroadband, and 1090ES (CLNP) are deployed.

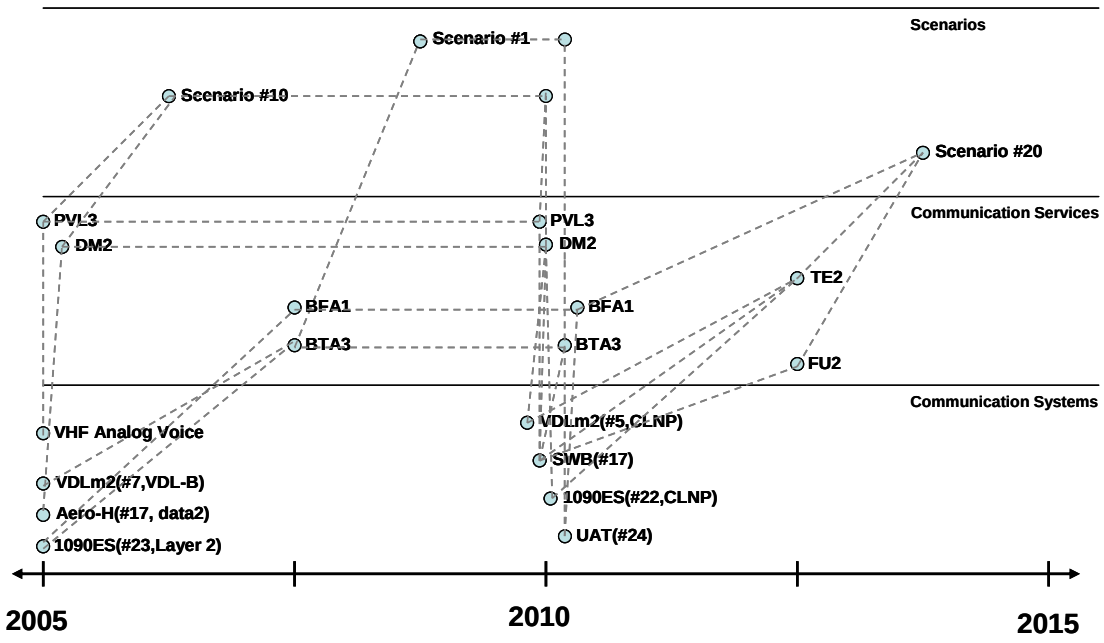

Figure 9: Flight Objects and AIM operational Scenarios.

Scenario #1 (Deploy FIS Nationally) and Scenario #15 (Enhanced Emergency Alerting) are repeated here as they also include aspects of Flight Objects and AIM. The description of their transition plans are addressed above in the descriptions of the previous figures.

Scenario #5 (Autonomous Hazard Weather Alert Notification) is special in that it requires any of four different voice and data communication services to meet its communication service needs. Broadcast voice can begin this scenario immediately in all airspace domains but remote, oceanic, and polar. Also in the near term Broadcast to Aircraft level 2 (BTA2) could support this scenarios using VDLm2 (VDL-B) and 1090ES (Layer 2). In 2010 and beyond, this scenario could be supported by VDLm2 (CLNP), SwiftBroadband, 1090ES (CLNP) and UAT through Broadcast to Aircraft Level-2 (BTA2), Data Messaging Level-2 (DM2), or Ground to Air Level-2 (FU2).

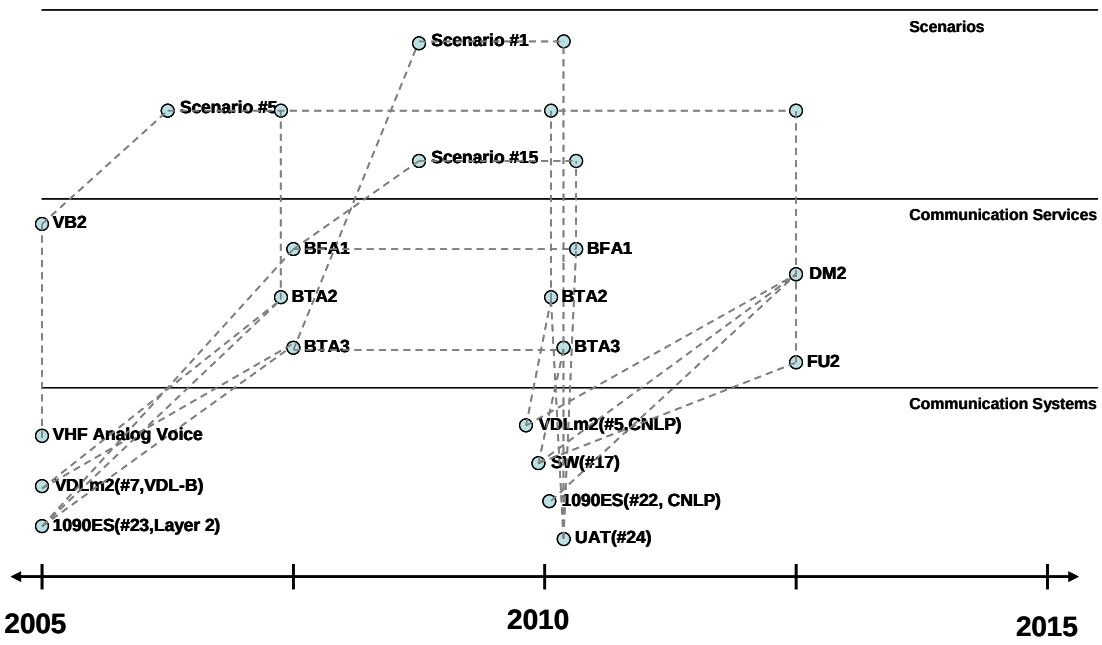

Figure 10: Weather and Surveillance Operational Scenarios.

6 MCNA Simulation, Emulation and Demonstration

This aspect of the MCNA work focused on the identification of simulation, emulation and demonstration (SED) activities to support the development of the MCNA architecture. For this project, simulation, emulation, and demonstration were defined as follows:

- **Simulation:** A model of system functionality.
- **Emulation:** A model of system functionality, where parts of the model functionality are carried out by a real or near-real system. It can accommodate system-in-the-loop and human-in-the-loop testing.
- **Demonstration:** A model and/or implementation of system functionality that can exhibit and/or validate a stated function, performance characteristic or user need.

To identify these types of activities to support MCNA development, first simulation, emulation and demonstration needs were defined. A survey of available tools and capabilities to support simulation, emulation and demonstration activities was then conducted. Finally, based on the identified needs and capabilities, a simulation, emulation and demonstration plan was formulated. These topics are addressed in the following subsections.

6.1 SED Needs

To identify MCNA SED needs, the general functionality associated with the MCNA concept as defined in the MCNA functional analysis was reviewed. Additionally, this functionality was considered in the context of implementing the target MCNA scenarios. A listing of a wide variety of MCNA SED needs is provided in Table 2-5 in the MCNA SED Report. Key MCNA SED <u>needs</u> extracted from this table include:

- Simulation models for existing and future (e.g. FCS) A-G communication links
- Simulation models for existing ATM ground networks (e.g. ACARS, ATN)
- Algorithms and simulation models for architectures that accommodate dynamic routing across multiple communication links
- Simulation tools that can accommodate modeling of mobility protocols (e.g. mobile IP)
- Capability to emulate ATC operations associated with target MCNA scenarios

- Capability to simulate and emulate avionics architectures to accommodate target MCNA scenarios

- Capability to demonstrate use of mobility protocols and dynamic routing

In addition to the general needs of the overall MCNA concept, it was considered informative to also identify key SED needs specific to MCNA target scenarios. The SED Report documents this perspective of MCNA SED needs for the key MCNA operational scenarios.

6.2 SED Capabilities

One of the requirements of MCNA SED activity was to[3]: "consider the unique facilities and capabilities that exist or are planned within the U.S. at NASA Centers, FAA Facilities, federally-funded organizations and companies, and to the extend practical, internationally". The approach used for this task included: 1) performance of an Internet search, and 2) a NASA GRC released Request for Information (RFI).

The results of these activities are presented in two tables in the MCNA SED Report. The first (Table 3-1) lists the results of the Internet survey of simulation/emulation tools and capabilities, and includes feedback comments, updates, and revisions to the results by the GNCSS-II partners.

The second output of this activity was a table associated with responses to the RFI. In January 2005, NASA Glenn Research Center distributed a RFI to industry requesting input on available or planned simulation, emulation, and demonstration capabilities specific to air traffic management. Ten organizations/groups responded to this RFI., including:

- BoozAllenHamilton
- Calian – SED Systems
- NASA Glenn Research Center & Computer Networks and Software, Inc
- Mulkerin Associates Inc and Computer Networks & Software, Inc.
- Lucent Technologies Inc.
- NASA Ames
- Ohio University
- Seagull Technology, Inc.
- Sensis Corporation

A summary of the responses is provided in Table 3-2 of the MCNA SED Report.

[3] GCNSS Phase II Statement of Work.

6.3 Mapping of SED Needs to Capabilities

To map SED capabilities to MCNA Needs, several Tools-to-Needs Mapping Matrices were created. First, a general (i.e. applicable to all MCNA scenarios) MCNA matching matrix was created. In this matrix, the tools are listed by row and the general MCNA Need categories distributed into columns. If a particular tool was capable of simulating, emulating, or demonstrating a need, an S, E, or D (respectively) was entered in the matrix at the intersection of the row (tool) and column (need). These matrices are provided as Figures 4-2 through 4-4 in the MCNA SED Report.

To further focus the mapping of tools to MCNA SED needs, a mapping of tools that may contribute to the satisfaction of the key general SED needs was generated. This mapping is provided in Table 4-5 of the MCNA SED Report.

6.4 MCNA SED Plan

With SED needs mapped to identified SED capabilities, the process of developing a SED plan began. This process included identification of SED tasks to address individual aspects of the MCNA architecture (e.g. link technologies, network technologies) as well as concepts to address integration of capabilities into a seamless mobile network (e.g. service portioning). A view of the resulting high-level MCNA SED plan is illustrated in Figure 11

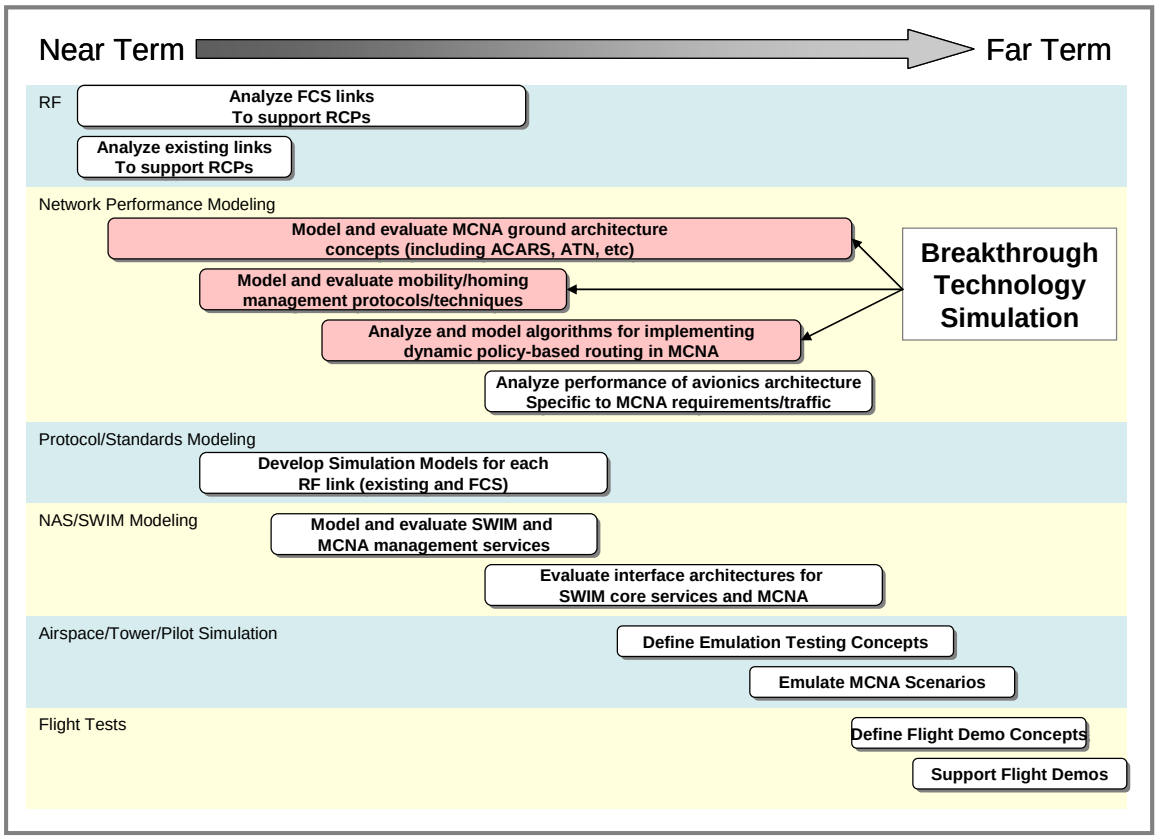

Figure 11: MCNA SED Plan.

Within this plan, a breakthrough SED opportunity for MCNA was identified. This relates to the implementation of simulation and demonstration capabilities to validate the feasibility, flexibility, and applicability of a highly flexible and integrated MCNA "system-of-systems" concept. Specifically, evaluation of specific service portioning and network integration concepts that result in an integrated set of A-G communication capabilities and aeronautical ground networks interact to provide a seamless set of A-G communication services to support MCNA operating scenarios. This concept includes the incorporation of mobility management and dynamic routing features within multiple aeronautical ground networks with interfaces to multiple A-G links to the aircraft.

The implementation of the MCNA opportunity described above requires the following:

- Identification of one or more MCNA target scenarios to be used to illustrate the MCNA system-of-systems concept
- Identification of communication classes specific to the selected MCNA target scenario
- Association of communication classes with two or more A-G communication links to be included in the simulation/demonstration

- Modeling or emulation of avionics elements to accommodate target scenario traffic and support dynamic routing

- Modeling or emulation of selected A-G communication links

- ***Key Task:*** Definition of algorithms and development of modeling/emulation capabilities for ground network elements supporting mobility management and dynamic routing/service partitioning in the aeronautical environment. The ground models/emulations should accommodate routing of data associated with selected target scenarios among at least two integrated aeronautical ground networks.

- Modeling or emulation of air traffic control operations accommodating the selected target MCNA scenarios.

As technologies, standards, modeling tools and actual products supporting mobile communication networks mature, the simulation/demonstration concept described here provides the opportunity to assess and validate the implementation of these emerging concepts in the aeronautical environment. This effort could provide a key role in validating concepts for transforming the current aeronautical communication capability to a highly capable, highly flexible “system-of-systems” MCNA that extends SWIM capability to the aircraft.

7 MCNA Certification

Certification is consistently cited as one of the key aspects of avionics development and a key driver in avionics costs. As important as avionics certification is, from the viewpoint of MCNA there are also additional systematic certification issues that need to be considered. The certification report describes the avionics and system certification processes. The term "certification" is used in the broadest possible sense; it includes the full range of approval activities, including functional approval of the avionics, issuing of an operating certificate for aircraft, and acceptance/approval of the communication system for MCNA-appropriate communications. This last issue is a thorny one, as there are specific requirements that have historically been applied to or associated with the provision of aeronautical safety related communications. As the MCNA study progressed, it became obvious that this "service certification" factor is equally important to those "avionics certification" factors. A discussion of the development of industry standards or other documentation upon which the FAA approval and certification activities can be based in include in the report.

The largest single challenge to system approval is the lack of a standardized FAA process for allowing or certifying communications *systems*. It seems that a process analogous to the current TC/STC process could be developed, but there is currently (mid 2005) no effort toward the development or approval of such a process. Recent conversations with members of FAA AIR, indicate that the specific organization is not positioned to accept or act on such submissions. Therefore, validating this approach, that is, obtaining FAA concurrence with both the *process* and the *documentation*, will be *the major challenge for system approval*. This leads to the principal conclusion of the certification report.

Conclusion 1: There is currently no FAA acknowledged process in place by which a commercial system can be approved for the transmission of safety services, including both ATS and AOC services. Current commercial systems used for these purposes have been approved and/or developed in an *ad hoc* manner appropriate to the needs of the community at the times of their development. There is, however, a *model* for the information required and the methodology by which that information could be developed. This model is contained in DO-270 [1]. A strawman consideration of DO-270 to Inmarsat Swift Broadband (SBB) services is contained in Appendix I to the certification report.

Other conclusions of the report include the following

Conclusion 2: There is no widely acknowledged paradigm for the use of commercial terrestrial telecommunications infrastructure for safety information, even though this use occurs every day. The software certification issues related to DO-278 are not well documented: in fact, it is not certain that DO-278 has been applied to such use. This suggests that there may be mechanisms by which the terrestrial telecommunication infrastructure model could be extended to include the air-ground links.

Conclusion 3: There is currently no FAA acknowledged process in place by which avionics suitable for use with a commercial system can be approved for the transmission of safety services, including both ATS and AOC services. There is a *model* for the information required and the methodology by which that information could be developed. This model is contained in DO-262 [7]. It is uncertain which organization within FAA would receive or approve such documentation as a basis for a TSO- or PMA-based approval.

Conclusion 4: Once the significant questions raised regarding system and avionics certification are resolved, the current aircraft certification process appears to be sufficient to support the approval for individual services. However, the current process *may not* be sufficient for anticipated future RCP applications.

8 MCNA Investment Analysis

The MCNA investment analysis focused on the following activities:

1) Identifying high value scenarios that will drive MCNA requirements.

2) Developing a strategy roadmap for how MCNA communication links and protocols will evolve over time and identifying potential gaps in service in the 2015 timeframe.

3) Prioritizing communication services.

4) Identifying and prioritizing enabling technology research opportunities.

5) Surveying available literature for studies that have quantified the benefits of MCNA technologies. (See MCNA Investment Analysis Report.)

The sections below summarize the results of these analyses.

8.1 Communications Service Analysis

In order to prioritize the communication services in terms of value, the communication services were mapped to the twelve (12) high value scenarios plus five (5) additional scenarios that didn't make it through the initial screening process but were deemed as potentially high value. The number of times a communication service was called out by a scenario was then tallied, Figure 12 . The purpose of this analysis is to identify the relative value and priority of delivering the identified communication services. The most prevalent services are Data Messaging, Broadcast from Aircraft and Trajectory Exchange. The least prevalent services are Video Exchange, Broadcast Voice, and SA (Selective Addressed) Voice. The implications of these findings are that the more prevalent the use of the service, the more the cost of delivering those services can be amortized over different scenarios.

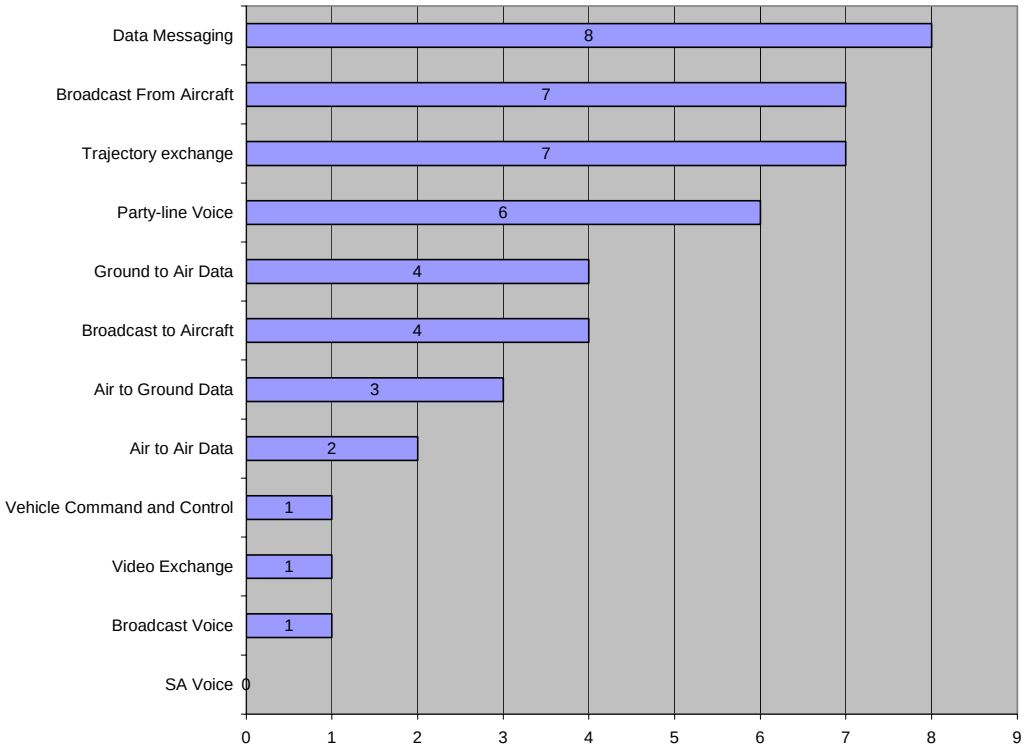

Figure 12: Communication Service Assessment.

8.2 Strategy Roadmap

A strategy roadmap was constructed to identify how communications links and services would evolve through 2025. A sensitivity analysis was conducted to analyze how well the strategies deliver the twelve (12) high value and five (5) additional high benefit/high risk scenarios identified in Section 3.1 The communications services analysis described in the previous section was used to help prioritize services and identify the most efficient set of links to achieve the high-priority operational scenarios.

Table 9: MCNA Strategy Roadmap.

	Air-to-Ground Voice (CONUS)	Air-to-Ground Data (CONUS)	Satellite Comm. (Polar, Remote, Oceanic)	Air-to-Air Communications	Airport Comm	Networking Protocols
2005	VHF Analog Voice	POA VDLm2	HF Voice HFDL Aero-H	1090- ES UAT	Not available	ACARS
2015	8.33 kHz Analog Voice	VDLM2 Satellite	HF Voice Aero-H Swift-64 SWIFT Broadband SDARS	1090-ES UAT	IEEE 802.11 IEEE 802.16	Multiple Protocols
2025	8.33 kHz Analog Voice P25	P34 Satellite	SWIFT Broadband SDARS	1090-ES UAT	IEEE 802.16	IP

An analysis was then conducted to determine how the 2005, 2015, 2025 and Target System Description (TSD) strategies support the high-value scenarios identified in Section 3.1.

Table 10: Evaluation of MCNA Strategies.

Legend: Yes / Maybe / No

	Scenario	Communication Services															
		Party-line Voice	SA Voice	Broadcast Voice	Data Messaging	Trjaecotry exchange	Broadcast to Aircraft	Broadcast From Aircraft	Ground to Air Data	Air to Ground Data	Air to Air Data	Video Exchange	Vehicle Command and Control	2005	TSD 2015	MCNA 2015	MCNA 2025
1	Deploy FIS-B Nationally						3										
5	Autonomous Hazard Weather Alert Notification			2	2		2		2								
10	Datalink to reduce routine workload	3			2												
15	Enhanced Emergency Alerting							1									
20	Optimize Runway Assignments					2		1	2								
25	Controller awareness of ACAS resolutions				1												
29	Aircraft push of security video and aircraft performance during emergency							2		2		1					
32	Push of Security advisories to aircraft				2												
16	Enhance Flight Data Management					2											
17	Interactive Flight Planning From Anywhere					2											
18	Oceanic Separatoin to RNP-4	4			2	2											
22	Flow Planning with distributed Schedule Recovery and Post Departure Rerouting					2											
30	ROA Control	2			2					1	1		1				
31	UAV Control					1	2	1	2	2							
38	Dynamic Resectorization	2			1	2	1	1									
13	Improved Surface Separation Assurance	3			1			1	2								
9	Shared Responsibility for Horizontal Separation	3						1			1						

The analysis shows that MCNA will deliver all of the high value scenarios in 2025 and all but two (ROA Control and Shared Responsibility for Horizontal Separation) by 2015. Moreover, the analysis shows that MCNA delivers more capability than the strategy described in the FAA Target System Description, primarily by embracing satellite technology.

The key areas of risk for the MCNA 2015 strategy are providing the Level-1 Air-Air data exchange and providing Level-1 Command and Control Datalink. The risks to providing these services subsequently result in risk to providing the ROA Control and Shared Responsibility for Horizontal Separation scenarios. The 1090-ES candidate link should provide the ability to support Level-1 Air-Air data communications. However, it is not clear that much effort is currently underway to focus on CLNP-based data exchanges via 1090-ES. The recommended approach to reduce risk in this area would be to introduce less stringent operational scenarios in the near term that leverage the use of CLNP over 1090-ES. A good candidate might be the Controller Awareness of ACAS resolution. If these messages were delivered via CLNP over 1090-ES, a migration

strategy could be initiated that would transition to the datalink being utilized to assist with ACAS resolutions and eventually relying upon the 1090-ES for full conflict resolution based upon intent exchange and trajectory negotiation.

The other high risk communication service for the 2015 strategy is Level-1 Vehicle Command and Control. This communication service demands low latency and very high availability and continuity. No individual candidate link is expected to provide sufficient performance in the terminal and en-route airspaces. Consequently, a combination of multiple candidate links is required. Swift-Broadband would make a good contributor to such an aggregate service but VDLm2 is not expected to provide sufficient bandwidth. The chances of supporting this scenario in the 2015 timeframe would be greatly increased by expediting the P25/P34 deployment cycle.

8.3 Enabling Technology Analysis

Four research areas have been identified as potentially high value research for MCNA. Each research area was assessed on its impact to overall MCNA cost, schedule and risk and the probability of success in achieving the stated objective. The highest value research area identified is “RCP process independent of an individual candidate link.” However, it also has the highest risk. From a risk-return perspective, the proposed projects are fairly close and there is no obvious priority.

Table 11: Enabling Technologies.

Topic	Description	Probability Of Sucess	Value Impact (1-5, 5 is highest)	Rationale
Common IP Stack	Develop a TCP/IP stack that is DO-178B certified to Level C or higher and made generally available to spur the development of lower cost IP- compliant avionics. Such a product would eliminate the need for each avionics manufacturer to develop a separate certified IP stack and recoup those development costs over a small set of avionics.	75%	2.0	Cost of IP-based avionics will increase resulting in delayed IP convergence. This would delay SWIM services to the aircraft.
SWIM Messaging	Develop and demonstrate the use of SWIM messaging as a means to introduce IP networking in the near term for ATS applications.	90%	2.3	Delayed deployment of IP networking resulting in a longer period of diverse networking protocols in the aeronautical industry
System Certification Process	Initiate a cooperative effort between FAA and interested parties to develop and approve an agreed-upon process for the submission and review of relevant data and the approval of commercial services and related avionics for AOC and ATS applications. One possible means for the service certification might be the development of System/Service Type Certification or System/Service Supplemental Type Certification. For avionics certification DO-262 should be used as a baseline for this effort.	60%	2.7	Reduced availability of commercial communication services, resulting in costly government-owned custom communication systems.
RCP process independent of an individual candidate link	Initiate a cooperative effort between FAA and interested parties, possibly including the efforts of RTCA Special Committees, to develop details of how RCP could be applied on an aircraft-by-aircraft basis, with the goal of simplifying or reducing aircraft equipage. The role of software defined radios should be considered within this context.	50%	4.0	Reduced availability of commercial communication services, resulting in costly government-owned custom communication systems.

8.4 Next Steps

The current MCNA investment analysis is driven by the scenarios identified and their relative value in terms of capacity (airspace and airport), flight path efficiency, safety and security. This approach helps identify priorities but doesn’t provide the business case for MCNA that helps justify budget allocations.

The next step for MCNA investment analysis will be to a) describe the reference case, b) describe the investment we propose in MCNA (this would include the link upgrades we suggest for 2015 and 2025, the enabling technology research we've identified, and anything else we think is appropriate to specify in the MCNA strategy, and then c) assess the value for making the MCNA investment. Ideally for item b) we would be able to articulate a set of alternatives and evaluate them on their relative merit.

9 MCNA Technology Gaps & Roadmap

This section identifies specific communication and networking gaps and the characteristics or limitations that need to be addressed by future technology investments to achieve total communication systems performance for the MCNA, including the extension of SWIM functionality to the aircraft. It includes the definition of technology gaps, process gaps, and culture gaps specific to development of the MCNA. Additionally, a ten year communications and network technology roadmap has been developed to address these gaps and to accommodate the envisioned 2015 MCNA architecture.

9.1 Gap Analysis and Roadmap Development Process

The methodology used to create the MCNA roadmap is shown in Figure 13.

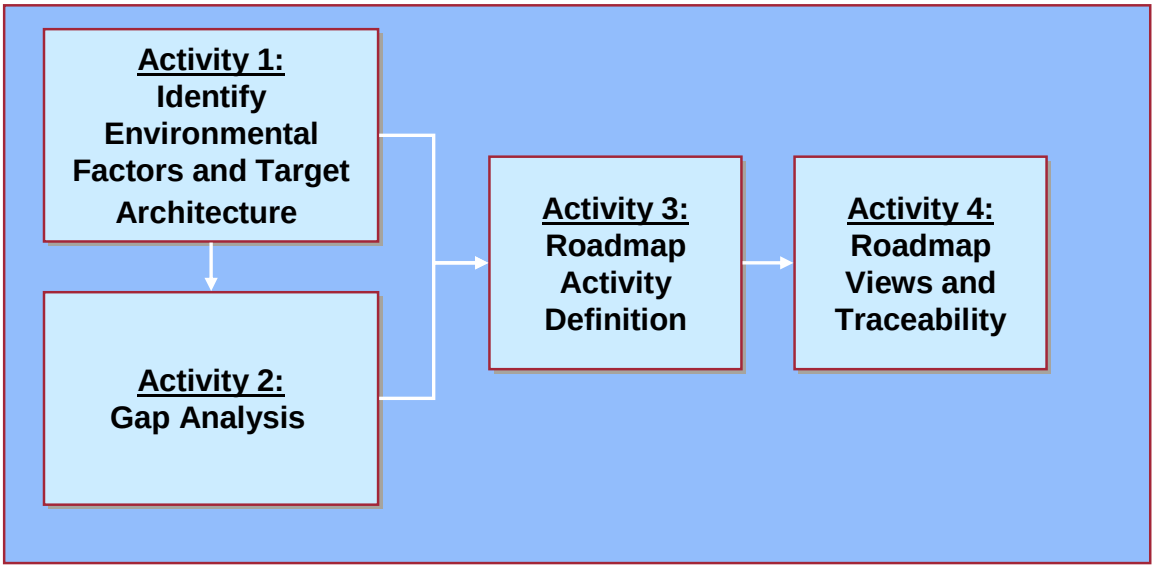

Figure 13: Gap Analysis and Roadmap Development Work Flow Diagram.

The figure above identifies the four major activities that led to the development of the MCNA roadmap. They included:

- Activity 1: Identify environmental factors applicable to MCNA development a target 2015 MCNA concept.
- Activity 2: Perform a gap analysis to identify technical, requirement, process and cultural shortcomings that need to be addressed to achieve the MCNA vision.

- Activity 3: Define major elements of the MCNA roadmap (major developmental steps and associated activities).
- Activity 4: Define a roadmap that lays out the developmental steps and the associated MCNA activities with defined relationships to environmental activities and traceability to gap analysis and 2015 functional concepts.

The resulting roadmap diagrams for MCNA illustrate relevant activities from two perspectives, the environmental perspective (addressing external but related activities that influence or are influence by MCNA) and the internal perspective (technical/process/policy activities that need to be addressed within the scope of MCNA development). The relationships between the activities of both perspectives are also addressed.

The following sections address each of the four activities noted above in further detail.

9.2 Activity 1 – Environmental Factors and 2015 Concept Formulation

Two issues were explored as a first step in determining the types of activities to include in the MCNA roadmap. The first was the range of activities occurring in the aeronautical and commercial environments that have some relevance to MCNA development. These activities are characterized as “environmental factors”. As noted above, they influence the MCNA development process or can be influenced by MCNA development activities. Knowledge of these activities helps to specify meaningful elements of the MCNA roadmap (e.g. can use inputs from environmental activities or provide outputs to environmental activities). The second issue concerned general concepts of MCNA capabilities expected or desired in the 2015 timeframe. Since the roadmap intends to lay out the necessary steps (and support investment planning) for achieving the 2015 target architecture, the type of capability/functionality expected in the 2015 timeframe needs to be captured. The following subsections address MCNA environmental factors and the general MCNA “target” concept for 2015.

9.2.1 MCNA Environmental Factors

As noted above, the MCNA development process is influenced by or may influence a number of activities/bodies of work that are external but related to the MCNA concept. To help document these activities, they have been grouped into the following five major categories:

- Improved Process Development
- Link Technologies
- Network Technologies

- Security
- System Integration

At the highest level, the categories can be viewed along with MCNA activities across the 10 year time span of interest for the MCNA roadmap (present through 2015). It is anticipated that some level of activity both within these environmental categories and within the MCNA will span most of the next 10 years. A detailed look at each environmental category is provided in the following sections. The final subsection (Section 9.2.1.6) summarizes all inputs/outputs between MCNA and specific environmental elements shown on the different environmental perspective figures.

The first environmental category is Improved Process Development. The diagram, pictured below in Figure 14, shows related activities in the definition of Required Communication Performance (as part of the Performance-based Aviation Rulemaking Committee Communication Working Group (PARC- CWG)) and in RTCA software certification areas (in Special Committee (SC) 205). It is expected that MCNA will utilize outputs of these activities as well as influence some of the work going on in these areas.

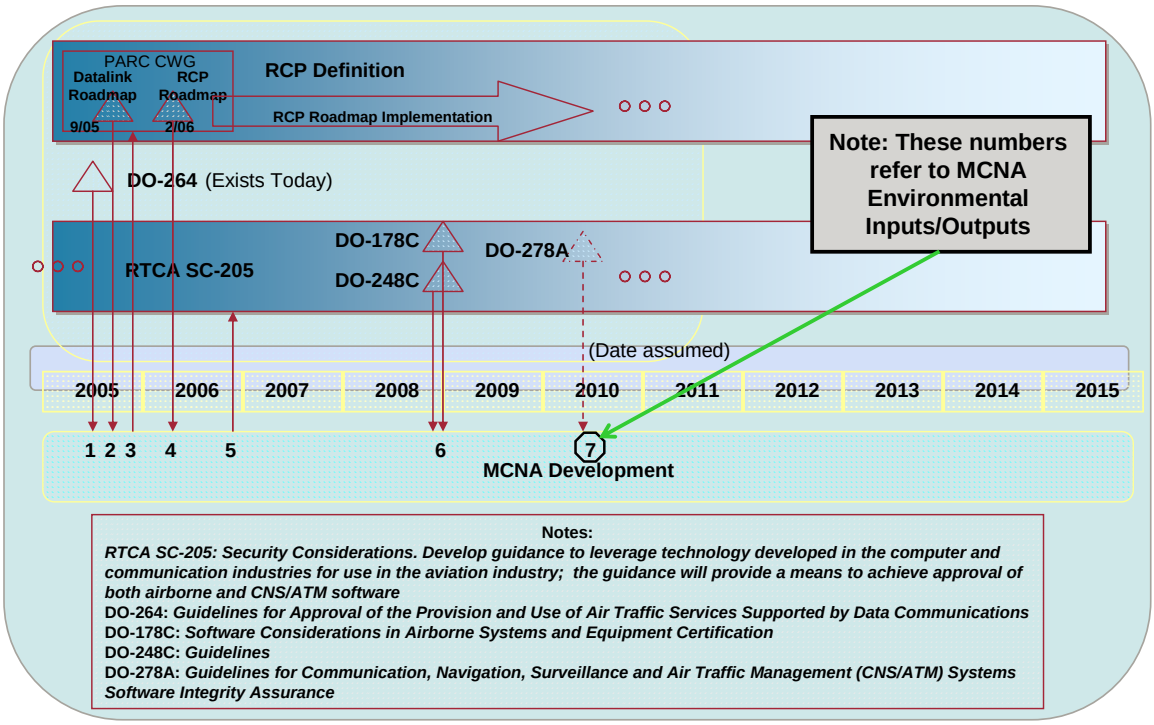

Figure 14: Improved Process Development Environmental View.

9.2.1.1 Environmental Category – Link Technologies

Figure 15 provides an overview of link technology environmental activities. It includes a range of items from specific link technology requirements/systems development to specific data link roadmap implementation activities within the FAA and the international community. It is anticipated that the MCNA development effort will benefit from the work products generated by the identified activities.

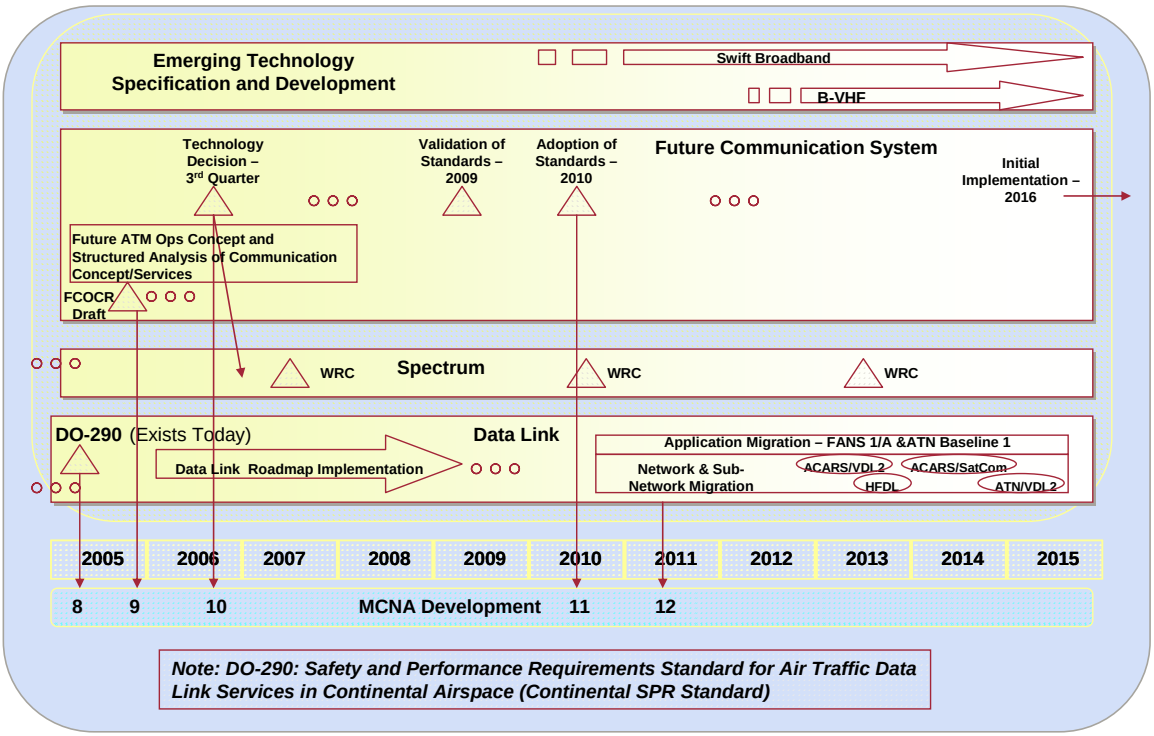

Figure 15: Link Technologies Environmental View.

9.2.1.2 Environmental Category – Network Technologies

Another environmental area of interest is activities related to network technologies. Figure 16 illustrates the timelines for relevant key areas of network technologies and their relationship to MCNA development. There are numerous efforts being carried out by the government and standards bodies that may be leveraged by the MCNA over the next ten years or which might be influenced by the MCNA development process.

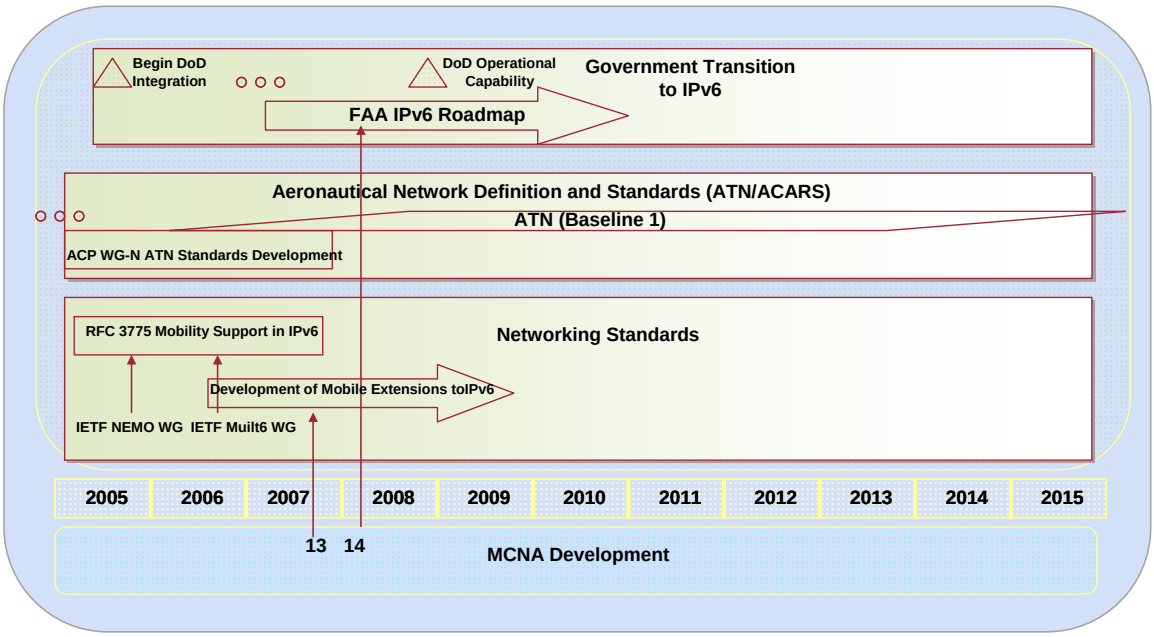

Figure 16: Network Technologies Environmental View.

9.2.1.3 Environmental Category – Security

Security will play a crucial role in the successful implementation of MCNA. Figure 17 shows how the development of various security standards and technologies will influence the MCNA development activities and how the MCNA work may influence on-going security efforts in the AEEC arena. It should be noted that due to lack of specific plans and timelines for some of the noted security activities, estimated timelines have been used.

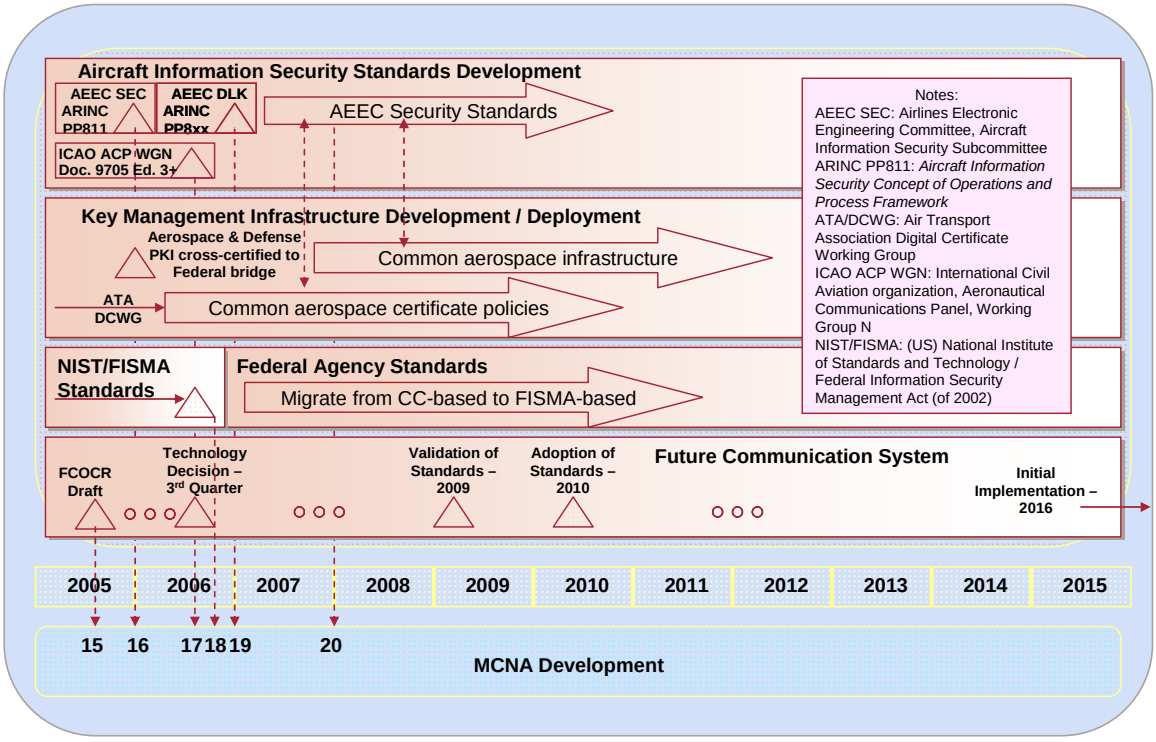

Figure 17: Security Environmental View.

9.2.1.4 Environmental Category – System Integration

A final environmental category to be viewed is system integration. The focus of the provided perspective, shown in Figure 18, is on the relationship of the MCNA development activity to SWIM, Software Defined Avionics (SDA), the FAA's En Route Automation Management (ERAM) system deployment, and the FAA's Future Telecommunication Infrastructure (FTI).

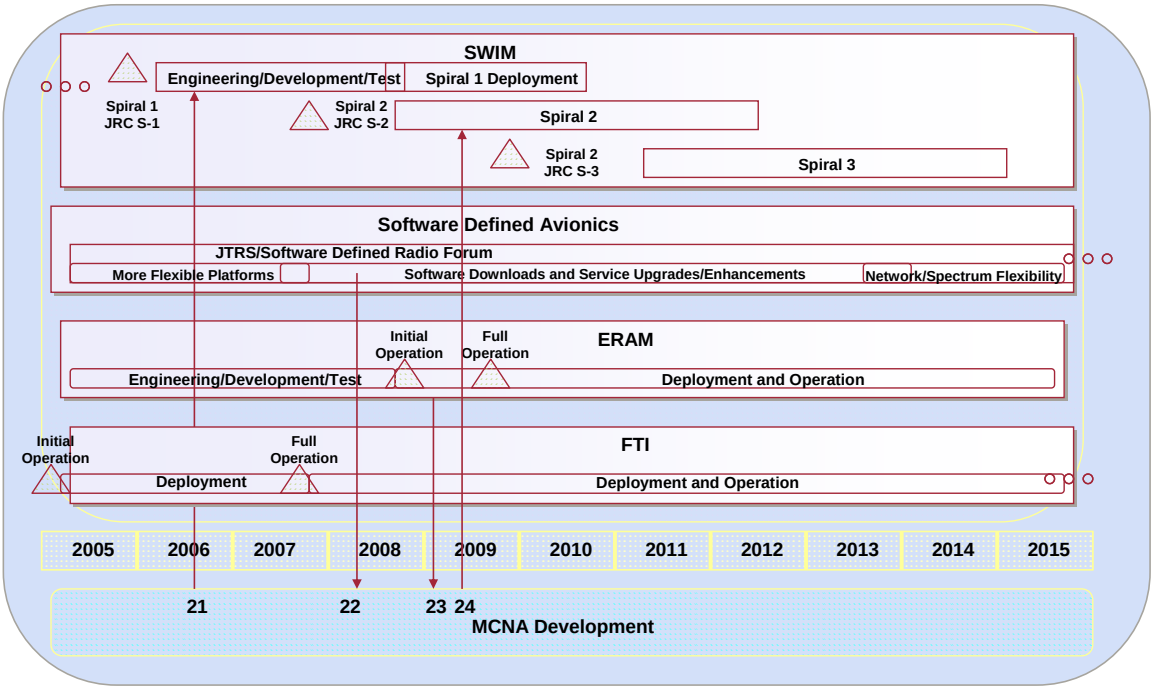

Figure 18: System Integration Environmental View.

9.2.1.5 Environmental Perspective – Inputs/Outputs Summary

In the different environmental views shown above, a range of activities external to but related MCNA where shown. Some of these activities may provide an input to or output from the MCNA development activity over the next 10 years. A complete and final detailed list of all anticipated inputs and outputs has not yet been defined. However, a subset of these inputs and outputs has been captured using vertical arrow lines numbered 1 through 24 on Figure 14 through Figure 18. A listing of these items is provided in Table 12. Note that in the Input/Output column, the classification is made from the MCNA perspective (i.e. input means input to MCNA).

Table 12: MCNA Environmental Inputs/Outputs.

	Item	Category	Input/ Output	Estimated Date	Applicability	Reference
1	DO-264 Guidelines for approval of ATS Supported by data link	Improved Process Development	Input	Current	Support development of certification process for use of commercial software and systems in MCNA architecture	RTCA document descriptions
2	PARC CWG Data Link Roadmap	Improved Process Development	Input	Fall 2005	Lays out roadmap to FAA datalinks that can be considered when validating the MCNA architecture requirements and transition plan	
3	Inputs to PARC CWG RCP Definition Process	Improved Process Development	Output	Late 2005	Bring MCNA outputs and RCP issues to the CWG for consideration; participate in CWG as appropriate	PARC CWG website
4	Inputs to SC-205 to request expanded scope and support development efforts	Improved Process Development	Output	2006	Supports MCNA inputs to defining a process for certifying commercial systems for ATC and AOC ops	RTCA SC-205 website
5	PARC CWG RCP Roadmap	Improved Process Development	Input	Early 2006	Supports refinement of MCNA architecture and transition plans	PARC CWG website
6	Updated documents DO-178C and DO-248C	Improved Process Development	Input	Late 2008, Early 2009	Supports MCNA inputs to defining a process for certifying commercial systems for ATC and AOC ops	RTCA SC-205 website and RTCA document descriptions
7	Update document DO-278A	Improved Process Development	Input	Late 2010	Supports MCNA inputs to defining a process for certifying commercial systems for ATC and AOC ops	RTCA SC-205 website and RTCA document descriptions
8	DO-290 AT data link performance & safety req.	Link Technologies	Input	Current	Support refinement of MCNA architecture and transition plans	RTCA document descriptions
9	Final Communications Operating Concept and Requirements for the Future Radio System - Draft	Link Technologies	Input	Late 2005	Support refinement of MCNA architecture and transition plans	ICAO WGW website
10	FCS Technology Decision	Link Technologies	Input	Late 2006	Should factor in to CWG Data link roadmap; consider when refining and validating MCNA architecture, requirements and transition plan	Output of CWG June 2005
11	FCS Standards	Link Technologies	Input	Mid 2010	Provides details to support detailed MCNA planning	
12	Aeronautical network capability roll-out (ACARS/VDLM2	Link Technologies	Input	2011	Implementation of aeronautical network capabilities allows for refinement of MCNA	

	Item	Category	Input/ Output	Estimated Date	Applicability	Reference
	, ATN, etc)				architecture and issues; transition plan development; and integration experimentation	
13	Support for definition of aeronautical extensions for mobile IPv6	Network Technologies	Output	2006	Supports refinement of MCNA architecture and transition plans	(Need refinement of RFC 3775 work plan)
14	Support for definition of FAA IPv6 Roadmap	Network Technologies	Output	2008	To support government transition to IPv6, it is assumed that the FAA will develop a roadmap. MCNA developers should participate in the definition of this plan	Used DOD transition timeline as a baseline for info
15	Final Communications Operating Concept and Requirements for the Future Radio System - Draft	Security	Input	Late 2005	Provides an initial set of operational security requirements and security categorization of information types, consistent with NIST, FISMA, and ARINC PP811	ICAO WGW website
16	AEEC SEC ARINC PP811	Security	Input	Early 2006	Provides an initial concept of operation for commercial aircraft information security, as well as a risk-based process framework for selecting and implementing security controls.	
17	ICAO Doc. 9705 Ed. 3+	Security	Input	2006 (?)	Enhancements to ATN Security SARPS (either as amendment to Ed. 3 or as Ed. 4) security framework to include confidentiality services.	
18	NIST/FISMA Standards	Security	Input	Late 2006	Completion of security standards and risk-based security management framework in response to FISMA legislation. Federal agencies (including DOT/ FAA) directed to migrate to this process for protecting critical information systems	
19	AEEC DLK ARINC PP8xx	Security	Input	Late 2006	Standardization of security framework for protecting AOC messages; expected to follow ATN Security framework specified in ICAO Doc. 9705, Ed. 3	
20	AEEC Security Standards	Security	Input	Early 2008 and beyond	Follow-on to ARINC PP811 recommendations,	

	Item	Category	Input/ Output	Estimated Date	Applicability	Reference
					expected to result in standardization of common security controls, common aerospace certificate policies, and common supporting key management infrastructure.	
21	SWIM Spiral 1 Development	Systems Integration	Output	Early 2008	Coordinate with SWIM engineering and development activities to ensure mobile users are accommodated in SWIM architecture (Spiral 1)	SWIM timeline based on information in SWIM transition plan
22	SDA Development Activities	Systems Integration	Input	2008	Support evaluation of future avionics technologies and architectures	
23	ERAM Capabilities/ Interface Descriptions	Systems Integration	Input	2009	Support concepts for service partition and integrated mobile networks to aircraft	
24	SWIM Spiral 2 Development	Systems Integration	Input	2009	Coordinate with SWIM engineering and development activities to add additional mobile users capability in SWIM (Spiral 2)	

9.2.2 Target 2015 MCNA Concepts

The roadmap developed for MCNA identifies specific activities to accomplish over the next ten years to achieve a target 2015 MCNA capability. Therefore, knowledge of this vision (what the MCNA plans to be in 2015) is an important aspect of roadmap development. As the MCNA development effort is in its infancy, there is not a full and detailed definition of the 2015 target architecture. Instead, information gathered and created during the MCNA tasks documented in this report have begun to outline the envisioned capability for the 2015 timeframe. It is certain that future work (as captured on the roadmap) will include refinement, elaboration, and validation of the envisioned MCNA target architecture. At this time, target architecture concepts have been inferred from material described in or derived from the MCNA Functional Analysis report and the MCNA Transition Plan report.

As noted in the MCNA transition plan, it is anticipated that existing (and potentially some new) communication capabilities will be present in the 2015 time frame. Based on the transition analysis, these communication capabilities will support the following communication services to a mobile user:

- Voice:
    - PL Voice (Service Level (SL) 1/3/4)

    - Selective Addressed Voice (SL 2)
    - Broadcast Voice (SL 1)
- Data:
    - Data Messaging (SL 1/2/3)
    - Trajectory Exchange (SL 2)
    - Broadcast to A/C: (SL 2/3)
    - Broadcast from A/C (SL 2/3)
    - Ground to Air Data (SL 3)
    - Air to Ground Data (SL 3)
    - Video Exchange (SL 2)
    - C2 (SL 3)

In the list above, the service level designation has been used to describe the level of capability (or service class) within each communication service category. The levels generally range from 1 to 3 or 1 to 4, with 1 indicating the most stringent performance attributes and the higher numbers the more basic service qualities. The activities in the MCNA roadmap should include activities that support the realization of these service classes within the NAS.

Also noted in the transition plan are the anticipated ATC operational scenarios that utilize MCNA that may be introduced over the next ten years. These include four scenarios in the safety and security arena (scenario numbers 32, 15, 25 and 29, as addressed in the transition plan); three scenarios in the flight objects/AIM arena (scenarios 19, 1, and 20); and two scenarios in the weather and surveillance arena (scenarios 1 and 5). As applicable and necessary, specific MCNA roadmap elements could be specified to contribute to the successful implementation of these operations in the NAS by 2015.

Another view of specifying the target 2015 MCNA architecture was created by reviewing the MCNA functions defined for the MCNA functional analysis and determining the desired or required level of capability for each function by 2015. This again helps to ensure that the elements of the MCNA roadmap include the necessary steps to reach the intended 2015 capability goal for MCNA development.

Table 13 below identifies the first three levels of MCNA functionality (from the functional analysis) and associates a capability level to the function for the 2015 target architecture. The capability level is specified in one of four ways:

- Full: full deployment of the functionality throughout the NAS
- Partial: partial deployment of the functionality within MCNA
- Trial: functionality exists, but only for trial purposes in selected areas
- None: functionality does not exist in the 2015 MCNA architecture

Additional clarification and comments are included in the table.

Table 13: Target 2015 MCNA Architecture Functionality.

Level 1 Function	Level 2 Function	Level 3 Function	Capability in 2015 Target Architecture	Comments
Provide Data Transport	Provide Naming and Addressing	Register Names	Partial	
		Allocate Network Addresses	Partial	Includes ACARS and ATN capability, which have rather static name allocation based upon ICAO number or tail number. With the roll-out of IPv6, more dynamic naming and addressing functions are introduced via DNS
		Resolve Address from Names	Partial	
	Manage Connections And Sessions	Authenticate User	Partial	These could be introduced by either secure ACARS (if ever applied) ATN version 2 or as part of new IP-based services.
		Authorize Access	Partial	
		Establish Connection/Session	Full	Generic to any datalink subnetwork (datalink capability exists in target architecture)
		Maintain Connection/Session	Full	Generic to any datalink subnetwork (datalink capability exists in target architecture)
		Terminate Connection/Session	Full	Generic to any datalink subnetwork (datalink capability exists in target architecture)
	Manage Routing Policy And Mobility	Allocate Flows to Subnetworks	Trial	Specific to applicable applications and available subnetworks (minimum functionality)
		Move flows between subnetworks	Trial	Gateway functionality implemented to provide this capability
		Create a subnetwork connection	Full	Generic to any datalink subnetwork (datalink capability exists in target architecture)
		Terminate subnetwork connection	Full	Generic to any datalink subnetwork (datalink capability exists in target architecture)
	Transport Data	Authenticate Data	Partial	

		Encrypt Data	Partial	
		Ensure Data Integrity	Full	
		Deliver packet to single user	Full	
		Deliver packet to groups of users	Partial	
		Deliver packet to all users	Partial	
	Provide QoS	Prioritize Packet Delivery	Partial	
		Pre-empt lower priority comm	Partial	
		Shape Traffic	Partial	
		Police Traffic	Partial	
Manage Data Transport	Manage Faults		Partial	Should tie in to FTI (and SWIM) capabilities
	Manage Configuration		Partial	Should tie in to FTI (and SWIM) capabilities
	Manage Accounting		Partial	Should tie in to FTI (and SWIM) capabilities
	Manage Performance		Partial	Should tie in to FTI (and SWIM) capabilities
	Manage Security		Partial	Should tie in to FTI (and SWIM) capabilities

9.3 Activity 2 – MCNA Gap Analysis

The next step contributing to development of the MCNA roadmap was the identification of technical, requirement, policy, and/or cultural gaps or shortcomings specific to the implementation of the MCNA architecture. During the development of MCNA requirements, architecture concepts (both avionics and ground), and transition plans, a range of shortcomings were identified and documented. Table 14 below provides a complete list of these identified MCNA gaps. Included in the table are recommended activities to address the shortcoming.

Table 14: MCNA Gaps/Shortcomings.

	Shortcoming	Recommendation	Category	Avionics Implications	SED Recommended
1	RCP does not clearly provide provisions to meet a service using multiple systems	Influence PARC CWG	Requirements		
2	RCP linearly divides expiration time allocations (in many cases, not necessarily all)	Influence PARC CWG	Requirements		
3	RCP seems to lack sufficient operational analysis behind many quantified performance requirements	Influence PARC CWG	Requirements		A common comprehensive modeling framework must be developed and applied to achieve this rigor of performance requirement derivation
4	Certain requirements such as multi-homing, policy based routing and priority/pre-emption are not clearly defined and universally applied	Influence PARC CWG	Requirements		
5	IP lacks sufficient mobility and multihoming capabilities as defined by ATN	Near term: Use SWIM messaging to achieve mobility; research application of messaging architectures to achieve multi-homing and policy based routing	Technology	Requires additional avionics on aircraft	Good opportunity to extend SWIM testbed to demonstrate and experiment with this concept
6	IP lacks sufficient mobility and multihoming capabilities as defined by ATN	Far term: Need to support and sponsor the development of IETF protocol extensions to IPv6 to support these capabilities at the network layer	Technology	New avionics will need to support IPv6 with these protocol extensions	Likely require protocol simulations and emulations to validate these new protocols in the aviation environment
7	New IP-based communication links should be able to support multiple classes of communications to provide better justification to equip	Develop and demonstrate techniques to safely and securely share a link for ATS, AOC, AAC and APC services	Technology / Cultural	Need to modify avionics IP architecture to support this capability securely	This is a key demonstration opportunity to overcome the political / perception aspects
8	Lack of a mechanism to multicast messages to	Transition towards IP-based A-G networking	Technology	Minor modification to IP	Demonstration of this capability

	Shortcoming	Recommendation	Category	Avionics Implications	SED Recommended
	managed groups of users	that can support IP-multicast extensions		router to support IP-multicast	would help improve political adoption of transition towards IP communications
9	Physical connection between A-G transceivers and sectors limits the ability to transition towards an agile NAS	This issues is primarily focused on voice; movement towards packetized voice with party-line line feature created at the application layer versus physical layer would introduce this flexibility	Technology / Culture	Packetized voice would require avionics and aircraft network modifications	Given the political nature of this issue, demonstrations leading to trials would be very important to initiate concept adoption
10	Lack of masquerading prevention in voice services	This is a significant issue that can also be addressed by migrating towards packetized voice. An operation issue still remains regarding how an authentication failure is handled.	Technology / Culture	Requires avionics modification for packetized voice services	Demonstration would help begin to address the operational concerns
11	Lack of masquerading in data services	Masquerading for data is a more easily solved solution; Secure ACARS, ATN security and other solutions exist. The key would be to demonstrate the technology to lead towards operational trials	Technology	Requires minor modification to CMU/MU	Demonstration would help begin to address the operational concerns
12	Certification cost of commercial avionics is a significant barrier to the introduction of additional low cost avionics to also enhance ATS communications	Development of processes to certify avionics / software based upon proven commercial use would allow a progression of datalink deployment for APC/AAC that could later also support AOC and ATS services following sufficient performance demonstration.	Certification		
13	During the near term, ACARS, ATN and IP links/networks will all coexist. Need a means to integrate these disparate networks to provide an integrated communication	SWIM messaging may provide an application layer routing capability that is transparent to the underlying networking technology. More research and experimentation would	Technology	Message router will introduce new avionics on the aircraft	SWIM testbed would provide a good platform to experiment and test

	Shortcoming	Recommendation	Category	Avionics Implications	SED Recommended
	service offering.	be required to evaluate the feasibility of such a solution.			
14	Need means of supporting address mobility for IP while maintaining efficient routing	The traditional two-part hierarchical IP addressing scheme (network id/host id) may not work directly in a wireless environment as the Mobile host may move from one subnet to another, but the packet address assigned to the mobile host is associated with a single subnet (the original). Some protocol solutions have been developed with various benefits/drawbacks	Technology		
15	Traditional transport layer protocol (i.e. TCP) implements congestion control mechanisms that may not be efficient in a wireless environment	With successive packet losses (which in a wireless environment can be attributed to link error more so than wired environments as well as to congestion) traditional TCP invokes a congestion control algorithm (TCP assumes data/ACK packet loss is due to congestion and reduces the size of the congested window by half). This can result in TCP providing degraded performance in wireless environments.	Technology		
16	May need to convert application layer protocol data formats for transport over bandwidth constrained wireless links	Wireless bandwidth is limited and much more expensive compared to wired networks. Also, the capabilities of the some wireless devices are limited, making it difficult to handle computationally and bandwidth wise expensive application protocols. If communicating with SWIM, there may have to be a conversion of data (such as character encoded data like XML) into a format that is less bandwidth intensive and	Technology		

	Shortcoming	Recommendation	Category	Avionics Implications	SED Recommended
		more suitable for Air Ground Communication.			
17	Need Topology Control Mechanism for the ad hoc MCNA network	In a mobile ad hoc network, there is a need to periodically or aperiodically reorganize quick and efficient manner that is transparent to users/applications (e.g. mobile user moving between ATN "islands" changes topology). This may require determining topology via exchange of topology information and recovery from major topological changes in the network.	Technology		
18	Need to determine MCNA routing protocols that coordinate efficiently with existing and planned link layer protocols and what routing protocols are offered by FTI, ATN, etc	Challenges faced by ad hoc routing protocols are (1) Mobility (2). Bandwidth Constraints (3). Error Prone and shared channel (4) Location dependent contention (5) Other resource constraints	Technology		Candidate Routing Protocols worth looking into are: Core Extraction Distributed Ad Hoc Routing Protocol, Zone Routing Protocol, and Zone Based Hierarchical Link State Protocol.
19	Some MCNA applications may require multicast routing capabilities	Tree based multicast structures are very unstable and need to be readjusted often to include broken links. On the other hand mesh based multicast routing structure may work well in a high mobility environment such as MCNA. The issues in designing multicast routing protocols are: Robustness; Efficiency; Control overhead; Quality of service; Efficient group management; Scalability; Security.	Technology		Candidate protocols worth looking into may be Mesh-Based Multicast Routing Protocols such as: On-Demand Multicast Routing Protocol, Dynamic Core-Based Multicast Routing Protocol, Forwarding Group Multicast Protocol, Neighbor Supporting Ad Hoc Multicast Routing, Core-Assisted Mesh Protocol, and Application-Dependent Multicast Routing such as: Role-Based Multicast,

	Shortcoming	Recommendation	Category	Avionics Implications	SED Recommended
					Content-Based Multicast, and Location-Based Multicast.
20	Conclusion 1: There is currently no FAA acknowledged process in place by which a commercial system can be approved for the transmission of safety services, including both ATS and AOC services.	A cooperative effort between FAA and interested parties should be undertaken to develop and approve an agreed-upon process for the submission and review of relevant data and the approval of commercial services for AOC and ATS applications. One possible means might be the development of System/Service Type Certification or System/Service Supplemental Type Certification.	Certification		
21	There is currently no FAA acknowledged process in place by which a commercial system can be approved for the transmission of safety services, including both ATS and AOC services.	In parallel with the development of the recommended process, a separate cooperative effort between FAA or NASA and a selected system/service provider should be undertaken to complete and validate the required documentation. Joint funding of such an effort, possibly by CRDA or other such vehicle, could provide the economic incentive for active service provider participation. Conducting such an effort in parallel with the development of the FAA approval process would provide the opportunity for real-time feedback and process improvement.	Certification	Without a *system* certification or approval process, the avionics question is moot.	
22	There is no widely acknowledged paradigm for the use of commercial terrestrial telecommunications infrastructure for safety information, even though	An effort should be made to assess how the use of terrestrial telecommunications infrastructure differs from the use of wireless telecommunications infrastructure. This assessment should	Certification	This is a consistency problem. Methods used to deal with the terrestrial infrastructure may be applicable to air-ground links as	

	Shortcoming	Recommendation	Category	Avionics Implications	SED Recommended
	this use occurs every day.	consider how similarities can be exploited to simplify the approval process. This task could be implemented by either, or both, of the groups established in accordance with the two previous recommendations.		well.	
23	There is currently no FAA acknowledged process in place by which avionics suitable for use with a commercial system can be approved for the transmission of safety services, including both ATS and AOC services. It is uncertain which organization within FAA would receive or approve such documentation as a basis for a TSO- or PMA-based approval. Including both ATS and AOC services.	A cooperative effort between FAA and interested parties should be undertaken to develop and approve an agreed-upon process for the submission and review of relevant data and the approval of avionics supporting commercial services for AOC and ATS applications. DO-262 should be used as a baseline for this effort. Because of the overlapping of the system and avionics approval processes, it is possible that this effort can be combined with that of Recommendation 1, above.	Certification	Without a process for accepting commercial infrastructure, including receivers, separate, costly avionics development will be required.	
24	(Same as above) There is currently no FAA acknowledged process in place by which avionics suitable for use with a commercial system can be approved for the transmission of safety services, including both ATS and AOC services. It is uncertain which organization within FAA would receive or approve such documentation as a basis for a TSO- or PMA-based approval. Including both ATS and AOC services.	Additional investigation into methods to encourage the use of commercial software in communications avionics should be undertaken. It is possible that the current SC-205 activities will encompass this issue. RTCA should be encouraged to review the SC-205 Terms of Reference and incorporate changes to accomplish this objective as appropriate.	Certification	Without a process for accepting commercial infrastructure, including receivers, separate, costly avionics development will be required.	
25	(Same as above) There is currently no FAA acknowledged process in place by which avionics suitable for use with a	NASA or FAA should consider funding an effort to develop a TCP/IP stack that is DO-178B certified to Level C or	Certification	Without a process for accepting commercial infrastructure,	

	Shortcoming	Recommendation	Category	Avionics Implications	SED Recommended
	commercial system can be approved for the transmission of safety services, including both ATS and AOC services. It is uncertain which organization within FAA would receive or approve such documentation as a basis for a TSO- or PMA-based approval. Including both ATS and AOC services.	higher and made generally available to spur the development of lower cost IP- compliant avionics. Such a product would eliminate the need for each avionics manufacturer to develop a separate certified IP stack and recoup those development costs over a small set of avionics. The effort should concentrate on a concise set of TCP/IP requirements based on avionics-specific tailoring of accepted standard, such as IPV6, a widely supportable, well-documented and traceable design, well-documented and traceable code in a widely supported language, such as C++, and a standard test suite. The effort would not encompass final instantiation-specific certification issues, which would be left to the equipment manufacturer.		including receivers, separate, costly avionics development will be required.	
26	Once the significant questions raised regarding system and avionics certification are resolved, the current aircraft certification process appears to be sufficient to support the approval for individual services. However, the current process may not be sufficient for anticipated future RCP applications.	A cooperative effort between FAA and interested parties, possibly including the efforts of RTCA Special Committees, should be undertaken to develop details of how RCP could be applied on an aircraft-by-aircraft basis, with the goal of simplifying or reducing aircraft equipage. The role of software defined radios should be considered within this context	Certification	Implementation of RCP may change the way aircraft are equipped and/or dispatched, and therefore, affect the avionics suite.	

9.4 Activity 3 – Developmental Phase Definition

MCNA roadmap elements have been defined based on the outputs of Activities 1 and 2 (Identification of Environmental Factors/2015 Target Architecture Concept). Specifically, three phases of MCNA development activities have been identified for the next 10 years consistent with the desired target capability, the gaps to be addressed and activities occurring in areas related but external to MCNA,. They include:

- Phase I: Systems Engineering Product Refinement; Process/Technology Investigation and Definition; Experimentation Planning
- Phase II: Technology Experimentation/Validation; Initial SWIM Integration; and Service Partitioning/Network Integration Planning
- Phase III: Technology Demonstration; initial service portioning/integrated network validation; and full SWIM integration (network centric operations)

The next subsection provides additional information about the activities associated with each phase and a detailed listed of roadmap elements.

9.4.1 MCNA Roadmap Phase I Activities

Phase I of the MCNA roadmap is divided in to two primary categories of activity: (1) on-going system engineering and process development; and (2) experimentation planning and technology investigation.

The system engineering activities build upon the work reported on in this document to refine, clarify and validate requirements, ground and avionic architectures, and transition plans. This work also includes re-evaluation of gaps/shortcomings to be addressed; development of certification processes and documentation (supporting use of commercial software/systems in ATC and AOC applications); and support for the definition of RCP through structured analysis of communication functions/capabilities.

The second aspect of Phase I is the development of plans for conducting experiments specific to the rollout of technology required for MCNA; investigation and development of MCNA network security requirements and technologies; and extension of mobile network protocols to the aeronautical environment.

9.4.2 MCNA Roadmap Phase II Activities

Building upon Phase I activities, Phase II includes initial technology experimentation and validation activities. This includes evaluation of technologies and concepts for future avionics architectures (including software-based or software-defined avionics). Other technology experiments also will be investigated.

Phase II also includes the validation of data link technologies for supporting defined communication service classes; the development and definition of service partitioning and network integration concepts; and planning for total system integration (among all stakeholders) and global interoperability. During Phase II integration with the SWIM testbed is also planned to develop and validate initial network centric operations extension to the mobile user.

9.4.3 MCNA Roadmap Phase III Activities

The final phase of the MCNA Roadmap focuses on validation and demonstration activities. Included in this phase are continued technology experimentation and technology demonstration; evaluation and validation of service partitioning and network integration architectures; and demonstration of initial integrated network capability (for a limited set of defined communication services and applications).

Phase III also includes additional integration with SWIM to support additional functionality and services as well as a native interface to SWIM.

9.4.4 MCNA Roadmap Elements

Based on the definition of the three phases of the MCNA roadmap (documented above), a set of specific roadmap elements were defined. These elements were defined to meet the gaps/shortcomings identified in the MCNA gap analysis; address recommended outputs of the MCNA SED Plan; and enable technologies defined during investment analysis activities. A summary of the specific elements for the MCNA roadmap is provided in Table 15 below.

Table 15: MCNA Roadmap Elements.

	MCNA Roadmap Element	**Developmental Step**
1	Refinement of Architecture, Requirements, Transition Plan	Phase I
2	Certification Process Definition/Standardization Support: Develop process for submission and review of relevant data supporting the certification of Commercial Systems/Software for AOC and ATS applications	Phase I
3	Certification Documentation Definition Support: Define required documentation for the process of certifying commercial systems for AOC and ATS applications	Phase I
4	Structured Analysis of Communication Services and RCP: Participate in RCP definition of end-to-end performance (including support for safety analysis)	Phase I
5	IPv6 Mobility Standards & IP-based Datalink Development (includes participation in Mobile IP Standards Organizations to define an aeronautical IPv6 with appropriate security, mobility and peer-to-peer	Phase I

	MCNA Roadmap Element	Developmental Step
	support)	
6	MCNA Network Security Analysis	Phase I
7	Experimentation Planning: Defining and planning specific experimental tasks supporting MCNA technologies and architecture concepts	Phase I
8	Future Avionics Technologies (e.g. SDA) and Architecture Evaluation	Phase II
9	Security Impact Analysis and Requirements Development	Phase II
10	SWIM Testbed Integration (initial mobile user capability for SWIM Spiral 1)	Phase II
11	Evaluation of Service Partitioning/Network Integration Technologies and Concepts	Phase II
12	Conducting Technology Experimentation	Phase II
13	Service Partitioning and Network Experimentation	Phase III
14	MCNA Technology Demonstration	Phase III
15	Additional SWIM Capability to Mobile User and Native Network Centric Operation Engineering	Phase III
16	Integrated Network Demonstration	Phase III

9.5 Activity 4 – MCNA Roadmap

Once MCNA Roadmap activities were defined, the next step was the development of the actual MCNA roadmap (which adds the time context to the roadmap elements). Two views of the roadmap were created. The first provides a high-level overview of the three planned phases of MCNA development over the next ten years. This roadmap view is shown in Figure 19.

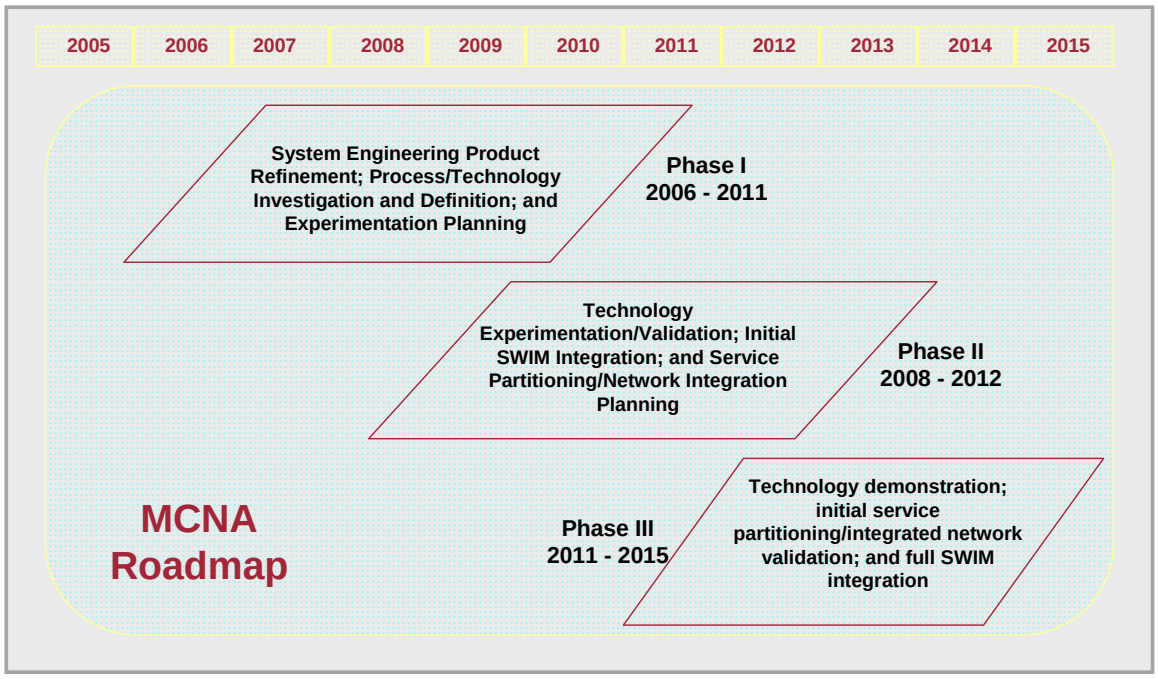

Figure 19: High-Level MCNA Roadmap.

The second MCNA roadmap view is shown in Figure 20. This view provides a more detailed layout of recommended activities to continue MCNA development and implementation over the next ten years. This more detailed roadmap was developed cognizant of inter-relationships among roadmap activities (e.g. planning activities specific to a topic would occur prior to experimentation; and experimentation would occur prior to demonstration) and relationships to environmental activities (as documented in Section 9.2).

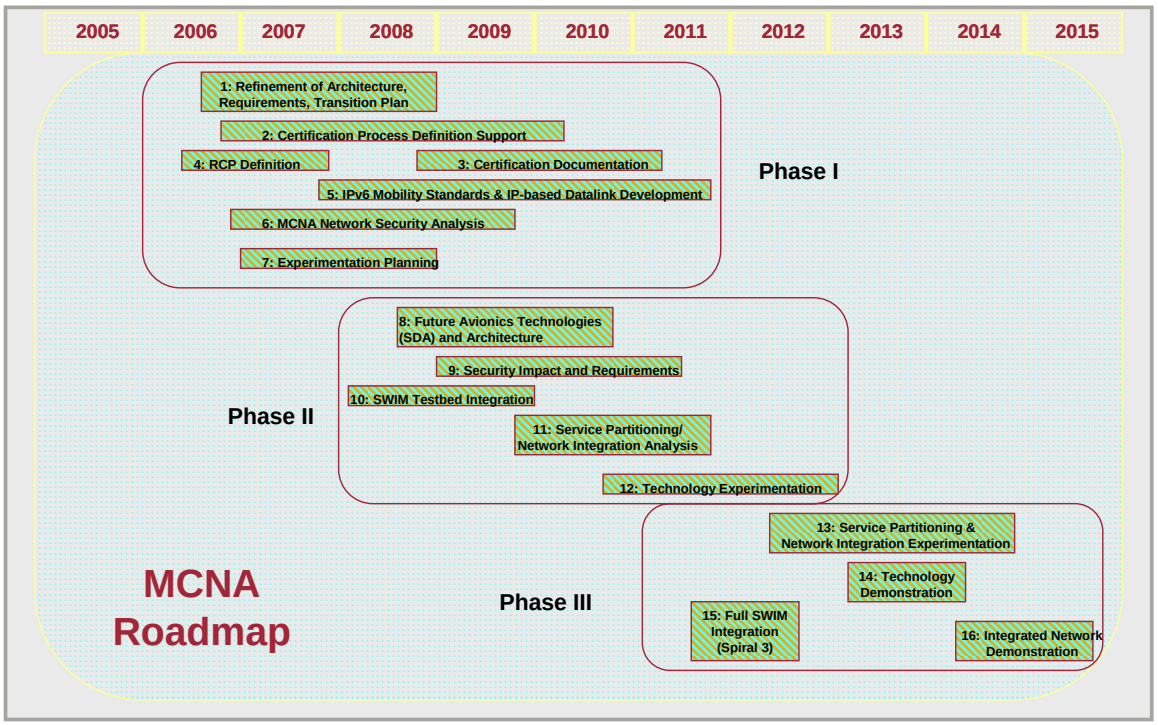

Figure 20: Lower-Level MCNA Roadmap.

The MCNA roadmap depicted above identifies the types of activities that need to be addressed over the next ten years. Some activities are relatively straight-forward (e.g. support RCP definition or certification process development). Other activities are broader in scope and should be refined and detailed during follow-on systems engineering activities supporting MCNA development (task element 1 of the MCNA roadmap).

9.6 Traceability

To ensure that the elements of the MCNA roadmap meet the roadmap objectives and the roadmap is complete, traceability was defined between the elements of the roadmap and related MCNA material developed as part of this study. Specifically, traceability was defined between the roadmap elements and:

- Gap/Shortcomings (defined during the gap analysis): to ensure that roadmap element exists to address all identified shortcomings

- SED Recommendations: to ensure the recommended simulation, emulation and demonstration activities were addressed by roadmap elements

- MCNA functions (to the level of capability specified in Section 9.2.2 above): to ensure the roadmap elements led to the level of capability expected in 2015

- Environmental Inputs/Outputs: to ensure that inputs to or outputs from MCNA development activities to specific environmental activities are associated with specific roadmap elements/activities.

The MCNA Roadmap traceability matrix is provided in Table 16 below.

Table 16: Traceability to MCNA Roadmap Elements.

	MCNA Roadmap Element	Defined Gaps	SED Recommendations	MCNA Functions	Envir. Inputs & Outputs
1	Refinement of Architecture, Requirements, Transition Plan	5,8,9		ALL	2, 3, 10, 11
2	Certification Process Definition/Standardization Support:	12, 20, 22, 23, 24, 25, 26			1, 4, 6, 7
3	Certification Documentation Definition Support:	21			1, 4, 6, 7
4	Structured Analysis of Communication Services and RCP	1, 2, 3, 4, 26			2, 3, 5
5	IPv6 Mobility Standards & IP-based Datalink Development	6, 8, 14, 15, 16, 17, 18, 19, 25	Model and demonstrate mobility protocols and dynamic routing	Transport Data; Provide QoS; Provide Naming and Addressing; Manage Routing Policy and Mobility	13, 14
6	MCNA Network Security Analysis	10, 11		Provide QoS	8, 15, 16, 17, 18, 19, 20
7	Experimentation Planning	5, 6, 7, 8, 10, 11, 14			12, 23
8	Future Avionics Technologies (e.g. SDA) and Architecture Evaluation		Simulation/emulate avionic architectures to evaluate support for		10, 11, 22

	MCNA Roadmap Element	Defined Gaps	SED Recommendations	MCNA Functions	Envir. Inputs & Outputs
			MCNA scenarios		
9	Security Impact Analysis and Requirements Development	10, 11		Provide QoS; Manage Security	8, 15, 16, 17, 18, 19, 20
10	SWIM Testbed Integration	5, 9, 16	Emulation mobile user interface to SWIM	Manage Connections and Sessions; Transport Data	21
11	Evaluation of Service Partitioning/Network Integration Technologies and Concepts	13	Dynamic routing/ service partitioning algorithms and architecture modeling	Manage Routing Policy and Mobility	12
12	Conduct Technology Experimentation	7, 8, 10, 11, 14	Model exiting and planned comm. lists to evaluate ability to provide RCP; evaluation of mobility protocols		12
13	Service Partitioning and Network Experimentation	13	Model and evaluate performance of integrated network and service portioning architecture		
14	MCNA Technology Demonstration	7, 8, 10, 11	Lab/Flight Demo of mobility protocols and dynamic routing		
15	Additional SWIM Capability to Mobile User and Native Network Centric Operation Engineering				24
16	Integrated Network Demonstration	9	Flight Demo		

10 Conclusions and Recommendations

The follow paragraphs summarize the key conclusions and recommendations from the MCNA effort under the GCNSS Phase II contract. While a significant aspect of the MCNA effort, a discussion of candidate links is omitted from the conclusions and recommendations because that subject is within the purview of the ongoing Future Communication Study (FCS). Furthermore, the MCNA is intended to provide seamless interoperability across any selected combination of candidate links.

10.1 Comparisons between MCNA and the ATN

The concept of MCNA exhibits many similarities with the ATN and justifies a discussion of the key differences. As an IPv6-based architecture, the proposed MCNA is in fact intended as replacement for Layers-3&4 of the ATN. At the time of ATN's development, structured networking protocols were in the development stages and ICAO selected the best option at that time. The commercial networking industry has since evolved, enhanced, adopted, and continually improved upon a competing standard protocol suite, TCP/IP. This divergence has resulted in the aviation industry backing a networking standard for A-G communications that has not benefited from the same process of ongoing implementation, monitoring, assessment and enhancement that has helped TCP/IP evolve into the robust global IT standard that it is today. Furthermore, depending upon proprietary networking protocols within a niche market greatly reduces the economies of scale that can be achieved using the TCP/IP protocol suite.

The intent of MCNA is to leverage technological enhancements over the past decade and merge these into the ATN to create a "best of breed" protocol suite to support A-G and A-A aviation communications. For example, the recent ATN work from the Edition Three SARPs on application layer security would be incorporated. The upper layers of ATN would remain unchanged, to the extent possible, since these were developed specifically for A-G datalink and are therefore the best available solution. At the time ATN was developed, layered networking and software architectures were relatively new concepts. Since then much more has been learned, through practical experience, about such architectural constructs. MCNA aims to integrate this knowledge and specific lessons learned with regard to the grouping of functionality within these layers, to create what could be considered a next generation ATN. MCNA has the potential to fully realize the ATN vision of a common standard for interoperability across all available data sub-networks.

To this end, ICAO has already recognized the advantages of TCP/IP for G-G communications and is activity investigating A-G opportunities. MCNA will also address the OMB mandate for federal agencies to transition to IPv6 based infrastructure.

10.2 Required Communications Performance (RCP)

MCNA is tightly coupled with the successful standardization and global acceptance of RCP. As such, MCNA has a vested interest to assure that the direction and progress of the RCP work is fully commensurate with the vision and goals of MCNA. In particular, the RCP framework must be defined such that a communication service can be addressed using one or more candidate links. As well, requirements such as mobility and multihoming need to be readdressed to determine if these design solutions are actually required or just proposed/recommended capabilities to help meet the intended performance requirements. Furthermore, the performance allocations for the various RCP levels must be derived through operational analysis. Basic operational analysis has been conducted for separation analysis by relating communication and controller intervention time into distance using aircraft closing velocity. Through this analysis, safe spacing distances can be related to navigation accuracy, surveillance accuracy and timeliness and communication and controller intervention latency.

A primary goal of RCP is to remove the existing barriers that eliminate candidate link alternatives, especially commercial alternatives, from consideration for support of ATS and AOC applications required for safety and regularity of flight. Ideally, RCP levels will be defined that support various levels of ATS and AOC applications. These RCP levels will be associated with quantitative performance requirements. Any candidate network solution that can meet these requirements would then be eligible for use with the supported datalink applications. This approach introduces an additional set of challenges associated with current modes of operation, security, architecture, policy and spectral use that must be addressed.

Unfortunately, the wider range of application of communication services with respect to navigation services is such that the framework needed to define a comprehensive set of RCP services may become very complex relative to RNP. Caution must be exercised to assure that the complexity of RCP does not become so great that the process of certifying for RCP is, in fact, more onerous than the current certification process. Historically, two of the most successful aviation communication systems (ACARS and FANS) were initially developed to provide useful capabilities for specific, limited applications that did not impose any safety critical certification requirements. Eventually, these systems were adopted and “grandfathered” into the NAS for a broader range of applications that included safety critical communications. This history should be carefully considered with respect to developing an RCP approach.

10.3 Common Networks for Safety of Life and Non-Safety of Life Communication Services

MCNA must leverage common and interoperable networks for ATS, AOC, AAC and even APC services. History has shown that it can be very challenging to develop a realistic cost benefit justification for a candidate link that only provides Air Traffic Safety (ATS) services. In contrast, the aviation industry is aggressively pursuing a variety of

candidate link alternatives to support Airline Operations Communication (AOC) services and Non-Safety of Life services (AAC & APC). Common infrastructure and avionics between both of these communication service classes could greatly enhance the benefit/life-cycle cost justification for the providers of both classes of services as well as that for the aircraft operators, and consequently expedite avionics installation and service adoption without requiring an FAA mandate.

A key enabling technology to achieve sharing of all classes of communications over common links is the deployment of mechanisms to guarantee QoS for all traffic classes supported. Such QoS mechanisms can be achieved through over provisioning, strict allocation of resource between service classes or priority, pre-emption and precedence (PPP) techniques. Demonstrating one or more of these techniques could help to overcome some of the preconceived notions regarding the need to segregate links and spectrum in order to assure link performance.

Airlines have no intention to migrate to ATN/CLNP for AOC, AAC or APC. IP is the dominant commercial networking technology and airlines are increasingly demanding IP-based links to reduce application development, IT expertise and avionics costs. With the majority of communication services migrating towards IP, it would seem prudent for the FAA to pursue a course of action that would enable a long term migration of ATS and AOC services over IP. As noted earlier, a pending OMB mandate will require federal agencies to transition to IPv6 based infrastructure within the next 5 years. It is worth clarifying that the proposed migration from ATN to IP would only affect Layers-3 & 4 of the ISO/OSI protocol stack while the upper layers of the ATN would likely remain unchanged to the extent possible.

10.4 Certification

The certification aspects of communication systems, avionics, datalink procedures and possibly RCP services are critical to the cost effective deployment of MCNA. No standardized process currently exists to approve a commercially owned and operated communication system for ATS applications. A possible framework for such a certification process was developed by RTCA under DO-270. However, an official process would require additional effort with direct cooperation and endorsement from the FAA. As the FAA considers options to reducing life cycle operational costs, it will have to decide which services and infrastructure the FAA does not need to solely provide, own and operate. A process for approval for use of commercially owned and operated infrastructure for safety of life services is critical. Without such a process, it is not possible for a commercial communication service provider to anticipate the effort and cost necessary to achieve certification. Without this information, the risk associated with attempting to achieve certification is too great for most communication service providers (CSP) to undertake.

A key desirable feature of this system certification process is a means for a candidate system and associated avionics to achieve certification through demonstrated performance. Specifically, a candidate system should have an option to initially be used

for APC and/or AAC services while performance metrics are collected to assess the ability of the candidate system to support AOC and eventually ATS services. This alternate certification path would provide a more cost effective means for commercial communication systems to attain certification to support Safety of Life services.

Another critical certification consideration is whether to allocate the certification level down to the A-G link avionics based upon the criticality of hazards from the supported applications. DO-290 suggests that the only failure mechanisms that result in major hazards (thus requiring Level-C certification) are a loss of integrity that results in the delivery of erroneous information or delivery to an unintended recipient. Since an A-G link is not capable by itself of guaranteeing end-end integrity, it makes sense to adopt the approach being used for Protected Mode CPDLC (PM-CPDLC) that moves the integrity requirement to the application and thereby relaxes the certification of the radio link avionics to Level-D. Providing a means to cost-effectively introduce commercial avionics in support of ATS applications will be crucial to assuring that MCNA services ubiquitous across all classes of airspace and aircraft, including GA.

10.5 Initiate Near Term Deployment of IP

Efforts should be conducted in the near term to introduce aeronautical communications services for AAC, AOC and eventually ATS purposes over IP links. Currently, the IP protocol stack has certain capability limitations which prevent it from accommodating some of the ATN requirements, specifically in the areas of multihoming, mobility and policy-based routing. While mobility is an unquestionable requirement, both multihoming and policy-based routing are design solutions that must be studied further to understand their criticality to the underlying communication system requirements. Regardless, the Internet Engineering Task Force (IETF) is current engaged in research to address this additional functionality within the IP protocol suite.

The ATN protocols were developed to support a wide array of aviation communication services. Many of these service classes are not yet under serious investigation for operational deployment in the foreseeable future. In fact, it is likely that the ATN/CLNP protocols will only ever be used to support messaging applications such as CPDLC and ADS. As such, it is prudent to investigate the use of IP networking protocols to accommodate these same messaging services that are planned for near term operational use.

An IP-based Message Transport Service (MTS) is a commercial technology that is rapidly growing in use and popularity and it has been selected as a key information transport service in the initial spiral SWIM design. Applying this SWIM MTS would address the short term IP mobility issues and provide a means to handle AAC, AOC and ATS message exchanges that are currently handled via ACARS. The SWIM MTS also provides mechanism to integrate robust information security mechanisms into the IP architecture. A further benefit is that SWIM MTS provides a means of interoperability between the various internetworking protocols in the NAS. Analysis, simulation and laboratory experimentation leading to flight trial of such an MTS used for CPDLC, ADS

and the extension of SWIM services to the aircraft would result in a demonstration of transformational capabilities.

An IP-based MTS tackles many of the immediate shortcomings of ACARS such as addressing and bandwidth efficiency. In parallel, ongoing research on IPv6 protocol extensions to address network mobility, multihoming and policy based routing should render acceptable and scalable solutions in time for these capabilities to be utilized by communication service classes requiring these functions. An IP-based MTS also provides a viable long term transition strategy for the introduction of TCP/IP protocols into the MCNA.

10.6 MCNA Should be Viewed as an Enabling Technology

Like SWIM, MCNA is an enabling technology that cost effectively enables operational improvements such as the “Agile NAS” operational concept advocated by the JPDO. Individual MCNA services, such as CPDLC, have been separately studied resulting in compelling cost/benefit justification when assumptions are made about the cost of the underlying infrastructure and avionics. Since MCNA provides a generic data transport capability, a much wider range of benefits will be enabled. The MCNA concept will require more up front investment to introduce this common approach for wireless data transport that will reduce overall lifecycle cost and complexity.

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12 ACRONYMS

A-A	Air to Air
A-G	Air to Ground
A/C	Aircraft
AAC	Airline Administrative Communications
AATT	Advanced Air Transportation Technologies
ACARS	Aircraft Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ACAST	Advanced CNS Architectures and System Technologies
ACD	Aircraft Control Domain
ACK	Acknowledgment
ADN	Aircraft Data Networks
ADS	Automatic Dependent Surveillance
AEEC	Airlines Electronic Engineering Committee
AISD	Airline Information Services Domain
ANCO	Advanced Network Centric Operations
AOC	Aeronautical Operations Communication
APC	Aeronautical Passenger Communication
AT	Access and Terminals
ATC	Air Traffic Control
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Service
BER	Bit Error Rate
BFA	Broadcast from Aircraft
BTA	Broadcast to Aircraft
CDRL	Contract Data Requirements List
CDT	Common Data Transport
CFS	Cabin File Server
CLNP	Connectionless Network Protocol
CNS	Communications Navigation and Surveillance
CONUS	Continental United States
CPDLC	Controller Pilot Data Link Communications
CSP	Communication Service Providers
CWG	Communication Working Group
DLK	Datalink
DM	Data Messaging
DNS	Domain Name Server
DOD	Department of Defense
ERAM	En Route Automation Management
ES	Extended Squitter
FAA	Federal Aviation Administration

FANS	Future Air Navigation System
FCAPS	Fault Configuration Accounting Performance Security
FCS	Future Communications Study
FD	Air to Ground Data
FIS	Flight Information Service
FIS-B	Flight Information Service - Broadcast
FISMA	Federal Information Security Management Act
FTI	Future Telecommunication Infrastructure
FU	Ground to Air Data
G-G	Ground-Ground
GA	General Aviation
GCNSS	Global Communication Navigation and Surveillance System
GRC	Glenn Research Center
HF	High Frequency
HFDL	High Frequency Datalink
IBM	International Business Machines
ICAO	International Civil Aviation Organization
ICOCR	Initial Communication Operating Concept and Requirements
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
ISO/OSI	International Standards Organization/ Open Systems Interconnect
IT	Information Technology
JPDO	Joint Planning and Development Office
MCNA	Mobile Communication Network Architecture
MOS	Mean Opinion Score
MTS	Message Transport Service
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCO	Network Centric Operations
NFS	Network File Server
NGSS	Next Generation Satellite Service
NIST	National Institute for Standards and Technology
O&M	Operation Maintenance
OI	Operational Improvements
OMB	Office of Management and Budget
PARC	Performance-based Operations Aviation Rulemaking. Committee
PBR	Policy Based Routing
PL	Physical Layer
PM	Protected Mode
PLV	Party Line Voice
PMA	Performance and Management Assessments
POA	Plain Old ACARS
PPP	Point-to-Point Protocol

QoS	Quality of Service
RCP	Required Communications Performance
RFC	Request for Comments
RFI	Request for Information
RNP	Regional Network Provider
ROA	Remote Operated Aircraft
RTCA	Radio Technical Commission for Aeronautics
RTO	Research Task Order
SA	Selective Addressed
SARPS	Standards and Recommended Practices
SBB	Swift Broadband
SC	Special Committee
SDA	Software Defined Avionics
SDARS	Satellite Digital Audio Radio Service
SE	Systems Engineering
SEA	SWIM Enabled Application
SEC	ETSI Security Technical Committee
SED	Simulation Emulation and Demonstration
SL	Service Level
SME	Subject Matter Experts
SoS	System of Systems
SoSE	System of Systems Engineering
SWIM	System Wide Information Management
TCAS	Traffic Collision Avoidance System
TCP	Tactical Control Panel
TCP/IP	Transmission Control Protocol/Internet Protocol
TCSP	Total Communication System Performance
TE	Trajectory Exchange
TNAS	Transformation of the NAS
TSD	Target System Description
TSO	Technical Standard Order
U.S	United States
UAT	Universal Access Transceiver
URL	Uniform Resource Locator
VDL	VHF Data Link
VDLm2	VDL mode 2
VHF	Very High Frequency
VOCODER	Voice Coder
WG	Working Group
WGW	Working Group of the Whole
XML	Extended Markup Language