

Airport Surface Network Architecture Definition

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Abstract

Currently, airport surface communications are fragmented across multiple types of systems. These communication systems for airport operations at most airports today are based dedicated and separate architectures that cannot support system-wide interoperability and information sharing. The requirements placed upon the Communications, Navigation, and Surveillance (CNS) systems in airports are rapidly growing and integration is urgently needed if the future vision of the National Airspace System (NAS) and the Next Generation Air Transportation System (NGATS) 2025 concept are to be realized. To address this and other problems such as airport surface congestion, the Space Based Technologies Project's Surface ICNS Network Architecture team at NASA Glenn Research Center has assessed airport surface communications requirements, analyzed existing and future surface applications, and defined a set of architecture functions that will help design a scalable, reliable and flexible surface network architecture to meet the current and future needs of airport operations.

This paper describes the systems approach or methodology to networking that was employed to assess airport surface communications requirements, analyze applications, and to define the surface network architecture functions as the building blocks or components of the network. The systems approach used for defining these functions is relatively new to networking. It is viewing the surface network, along with its environment (everything that the surface network interacts with or impacts), as a system. Associated with this system are sets of services that are offered by the network to the rest of the system. Therefore, the surface network is considered as part of the larger system (such as the NAS), with interactions and dependencies between the surface network and its users, applications, and devices. The surface network architecture includes components such as addressing/routing, network management, network performance and security.

Introduction

The current state of most airport surface communication networks is fragmented [1], while the requirements placed upon the Communications, Navigation, and Surveillance (CNS) systems in these airports are rapidly growing and integration is urgently needed if the future vision of the National Airspace System (NAS) [2] and the Next Generation Air Transportation System (NGATS) 2025 concept [3] are to be realized. This problem is compounded by the fact that airport surface communications systems at most airports today are built on legacy circuit-based concepts, rather than modern packetized Internet protocols. The ground-ground communications systems being used by the Federal Aviation Administration (FAA) alone, for instance, are diverse and lack the capability to support systems-wide interoperability and information sharing. To address this and other problems such as airport surface congestion, the Surface ICNS Network Architecture team at NASA Glenn Research Center (GRC) has assessed airport surface communications requirements, analyzed existing and future surface applications, and defined a surface network architecture that is robust and flexible to meet the current and future needs of airport operations.

The process of gathering requirements, performing analysis and defining a surface architecture that is robust and flexible to meet the current and future needs of airport operations is very challenging and complex, especially in the post-911 environment. To develop a surface architecture in the context of today's airport communications and legacy technologies being used at airports in the United States and through the world is enormously difficult. In order to meet the objective of this task, the GRC team selected the System Engineering (SE) approach or systems methodology for assessing surface communications requirements, performing surface applications analysis, and defining a set of architecture functions that will help design and implement any future surface networks.

The system engineering approach is presented in the Methodology section of this paper. The rest of this paper presents the results of surface communications requirements assessment, surface applications analysis, and surface network architecture functions and their definitions.

Methodology

The methodology used for gathering requirements, performing analysis, and defining the Airport Surface Network Architecture is based on the System Engineering (SE) approach. This SE approach has been embraced by the FAA as “proven practices” [4] deemed most appropriate to analysis, planning, design, acquisition, lifecycle support, and management of the Federal Aviation Administrations programs. The systems methodology approach is selected for developing the Airport Surface Network Architecture Definition because the process of gathering requirements, performing analysis and defining a surface architecture that is robust and flexible to meet the current and future needs of the airport operations is enormously complex.

In the early phase of Surface Network Architecture Definition (SNAD) development, it was also obvious to the NASA GRC team that the traditional approach to networking for the airport surface would not work, because this traditional approach focuses primarily on capacity planning or bandwidth, while ignoring other components of network resources that are important to the performance of airport operations. Based on [5], the surface network can be defined as a part of the larger system (such as the NAS), and associated with the system are sets of services that are offered by the network to the rest of the system. In general, the flows of information between network analysis, architecture and design are illustrated in Figure 1.

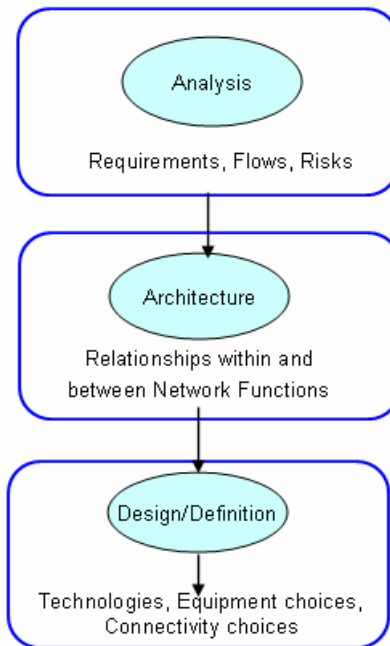


Figure 1: General flows of information between network analysis, architecture and design

Through the above process, the surface communications requirements can be assessed and the existing and future surface applications can be analyzed for communication characteristics. Based on the information derived from requirements assessment and applications analysis, the Surface Network Architecture Definition can be developed. This architecture consists of the major functions or components as the building blocks of any future surface networks that may be designed and implemented to meet the needs of airport operations. Although there

are other functions such as surface wireless infrastructure, applications services and storage, which can be considered as components of the surface network architecture, this paper will only examine the following common functions: addressing/routing, performance, network management and security.

Surface Networks Requirements Analysis

The development of an Airport Surface Network that supports legacy communications systems and incorporates new technologies (such as Third Generation Wireless Services and Wireless Local Area Networks) was an important part of the Advanced CNS research effort undertaken by NASA under the Space Based Technologies Project. In order to have a better understanding of the current requirements and future communication needs, NASA decided to contract with the Scientific Applications International Corporation (SAIC) (formerly Trios Associates, Inc.) to examine the current and future airport communications requirements with an eye toward developing a high level set of operational requirements for an Airport Wireless Surface Network (AWSN). The results of this study [6] are summarized below.

1. Airline Operations Communications Systems Requirements

In this study, Dallas Fort Worth International Airport (DFW) was selected, because it met the Level 12 traffic study requirement by NASA. DFW has the third largest number of aircraft operations in the United States and it is home to AMR Corporation. AMR Corporation is parent of American Airlines (AA) and American Eagle (AE), the biggest airline in the country. AA and AE comprise 73% of all aircraft operations at DFW. In this study, the remaining airlines’ requirements are extrapolated from the AA’s results (backed up by an interview with Continental Airlines). In addition, AA has a major maintenance base at DFW that added significantly to the communications loading, and AA is also one of the most sophisticated users of communications technology in the passenger airline business. The estimated bandwidth requirements are provided in Table 1.

Airline	Estimated Bandwidth Requirements (voice & data)
American Airline DFW	45 Mbps
All Airlines at DFW	58 Mbps
All Airlines at a typical airport	69 Mbps (when difference in total number of airline operations between O’ Hare & DFW was factored in.)

Table 1: Bandwidth Requirements from SAIC’s Study

Wireless communication for all the airlines mainly involves VHF radios for communications between the airline ramp and the pilot. For other surface activities, trunk radio systems operating in the 400 or 800 MHz ranges are used. At DFW, approximately 70 frequencies are available for airline to pilot communication and around 180 frequencies are used for airline trunk radio systems.

2. FAA Communication Systems

DFW was a good choice for examining FAA surface communications because its configuration is unique with two active Air Traffic Control Towers (ATCT): one for air traffic using the east side of the airport and one for the west side. Each tower has its own communication needs and the need to communicate to coordinate when traffic crosses from the east to west or west to east side runways.

DFW’s FAA communication systems utilize many diverse media types such as copper, fiber, microwave, and wireless technology and span various FAA buildings around the airport. These systems carry ATC voice, surveillance, weather, and other traffic that are critical to DFW airport operations. These communications systems also have a plenty of redundancy and diversity built in to them as they were designed with criticality and aviation safety in mind.

DFW is also home to an ASDE-X demonstration system. ASDE-X using ADS-B and Multi-lateration combined with ASDE-3 radar enhances situation awareness for the TRACON, the AA Ramp Control Tower, and the Airport Board.

The bandwidth requirement for FAA communications at DFW was estimated from analysis, as follows:

- 23 Mbps is required between the TRACON and the two towers, and
- 12 Mbps is required from the TRACON to other FAA facilities on airport
- For a busy airport like Chicago O'Hare, these numbers would be extrapolated to 28 Mbps and 15 Mbps respectively.

Spectrum Analysis for FAA systems revealed that around 152 frequencies are being used for ATC voice communication, radio navigation and other services.

3. Airport Operations Communication Systems

Because of its size and breadth, DFW provided an opportunity to examine the use of communications by the Airport Board. It should be noted that the U.S. Department of Homeland Security raised the terror alert threat level to Orange during the course of this study. The threat level change made it difficult to capture all DFW Airport Board communications requirements. However, based on the network diagrams and responses to the questionnaires obtained from the airport board, the result for the portion of this study was estimated, as follows:

- The network loading was estimated to be less than 10%.
- Since the network runs at 100 Mbps in the Access Layer, any service on the airport board network cannot have a bandwidth requirement greater than 10 Mbps within the airport.
- Communications to the outside world was close to 7 Mbps based on the infrastructure available.

Note that the DFW Airport board actively uses a secure land-mobile radio system that operates in the 800 MHz range with about 32 frequencies as well as a 400 MHz radio system with 6 frequencies.

4. Tenant Communications Systems

Trunk radio systems are used by most airport tenants as their main means of communication. These radio systems operate mainly in the 450 MHz band. Radio systems used by various concessionaires and government agencies also operate 30 MHz, 150 MHz and 170 MHz ranges.

Passenger needs were captured by assuming that passengers would utilize an 802.11g wireless network. Bandwidth requirements for passengers are assumed to be equal to the maximum provided by the standard.

In addition to the FAA and AA/AE, DFW is home to significant United Parcel Service (UPS) and Federal Express (FedEx) cargo shipments. This provided the study with an opportunity to not only look at additional airlines, but also examine the use of wireless networks by two major airport tenants who use wireless networks as part of their day-to-day business.

UPS' LAN in their package sorting facility was assessed to gather the land-line and wireless communications requirements. Their wired LAN consists of a single LAN with Cisco switches/routers interconnected by fiber and copper. The network does not have outside access to any other entities on the airport; instead a phone system is used for this function. A fractional T-1 is used for off airport access to their corporate head-quarters. An 802.11b wireless LAN system is used for scanning packages from loading gates.

5. Existing Systems Assessment

Specific interface characteristics, protocols, data rates of the communications systems used by airlines were collected. Databases with FAA and airport tenant information are provided with the final report [6]. A summary of the analysis of the data for all stakeholders is included in Section 5 of that report.

6. Services Description and Criticality Evaluation

From the document search and on-site interviews the SAIC team was able to determine the criticality of the applications that might traverse the AWSN. The following is a summary of this evaluation:

- For airline operations, any service interruptions that affect schedules are critical.
- For FAA, all communications, navigation, and surveillance systems are critical.
- Hazardous weather systems are also considered critical.
- For the airport board, police, fire, and emergency as well as other airport operations in the surface movement area are considered critical.

7. Current Wireless Systems

To get a better understanding of the frequencies in and around DFW, SAIC obtained the output of the National Telecommunications and Information Administration (NTIA) frequency database for an 8 mile radius with origin being at the center of the DFW area. The Aeronautical Frequency Committee (AFC), operated by ARINC for the industry, provided the Federal Communications Commission (FCC) equivalent that included the ARINC used frequencies at DFW. These outputs were combined into a single database, which contains approximately 20,000 frequency assignment records, with a minimum of overlap (approximately about 500 records). When scaled down to address only the frequencies used inside the fence line of the airport, there are approximately 4800 assignments.

With the above information gathered, SAIC was able to determine the communications traffic loading requirements for the AWSN based on the current copper, fiber and microwave systems.

8. Proposed Set of Requirements

The main result of this study is a set of proposed requirements including technical, performance, security, system safety and policy aspects whether the AWSN is used for wireless, wire-line replacement, aircraft to controller voice, or data link systems. Below is a subset of the performance requirements:

- The AWSN, for Aircraft to Ground, communication shall meet the required communication technical performance of 770 ms 95% of the time and the continuity, availability and integrity numbers as specified in [7].
- The AWSN shall have the following minimum data rates for each segment of the user community listed in Table 2.
- The AWSN shall be expandable, at a minimum, to 200% of its minimum data and voice capacity requirements to support growth.
- The AWSN shall be capable of supporting end-to-end services that have 0.99999 availability with a six second mean-time-to-restore in accordance with FAA Order 6000.36 and the NAS-SR-1000.
- The AWSN latency, when used as a wire-line replacement to an ATC voice and data communication site, shall not exceed 25 ms in one direction.

Stakeholder	Minimum Data Rate
FAA	28 Mbps (TRACON to Tower); 15 Mbps (TRACON or ATCT to RTRs, NAVAIDS, ASR-9 Radar, DBRITE, Weather Sensors, etc.)
Airlines	69 Mbps
Airport	7 Mbps for data
Passengers	54 Mbps (based on 802.11g)

Table 2: Estimated Data Rate for User Community

Surface Application Requirements Analysis

Applications requirements are generally requirements that are determined from application information, experience, or testing [5]. Application information that has been collected and analyzed for each of the current and future surface applications is necessary to understand the requirements imposed by applications upon the communications systems. These major applications were categorized, as follows:

- Air Traffic Management (ATM)
- Aeronautical Operational Control (AOC)
- Airline Administrative Communications (AAC)
- Airport Operation Communications

The current and future applications for ATM and AOC are listed in Table 3 through Table 6. An example of current Predeparture Clearance (PDC) communications characteristics are shown in Table 7. For more information about other communications characteristics please see [8].

Current ATM Applications	Description
Pilot-Controller Communications	Pilot-Controller Communications includes Predeparture Clearance (PDC), Taxi Clearance and Oceanic Clearance.
Context Management (CM)	CM applications initiates and maintains data link connection between an aircraft and ground station
Airport Terminal Information Service (ATIS)	ATIS is the continuous broadcast of recorded non-control information in selected high activity terminal areas.
Notice to Airmen	Time-critical aeronautical information disseminated via the National Notice to Airmen (NOTAM) System.
Cockpit Voice	This is an ATC-related application.
Remote Transmitter/Receivers (RTR)	RTRs are responsible for carrying critical ATC radio traffic between ATCT/TRACON and pilots.
Tower Data Link System (TDLS)	TDLS is a user-friendly computer interface to support multiple concurrent airport air traffic control tower applications on one platform.
METAR	International Aviation Routine Weather Report
TWIP	Terminal Weather Information to Pilots
MDCRS	Meteorological Data Collection & Report System, which is an ATC advisory service.
LLWAS	Low-Level Wind Shear Alert System, which is used to measure wind speed and direction at remote sites around airport terminal.
AWOS	Automated Weather Observing System
ASOS	Automated Surface Observing System
ITWS	Integrated Terminal Weather System
RVR	Runway Visual Range provides real-time RVR data to FAA facilities and air

	carriers.
Surveillance	This includes Airport Surveillance Radar (ASR-9), Airport Surface Detection Equipment (ASDE-X/ASDE-3), Surface Movement Advisor, Airport Movement Area Safety System (AMASS) and Digital Bright Radar Indicator Tower Equipment (DBRITE).
NAVAIDS	Airfield Navigational Aids (NAVAIDS) are small sensors located around the airport that give aircraft information for landing and takeoff.
ILS	Instrument Landing System helps aircraft land safely on a runway and it consists of a Localizer, Glide Slope, and Markers.
MLS	Microwave Landing System
Distance Measuring Equipment	Provides distance separation measurement between an aircraft and the ground unit.
VOR	VHF Omnidirectional Ranging provides magnetic bearing information for long range navigation (up to 175 NM).
Non Directional Beacon	Provides pilots with indications of bearing to ground transmitting station.
TACAN	TACTical Air Navigation (TACAN) is a military long range navigational aid sited with or instead of a VOR.
LORAN-C	Long Range Navigation C is a civil marine radio navigation system used in coastal waters for up 1200 miles.
WAAS	Wide Area Augmentation System is a safety-critical navigation system being developed by FAA.
LAAS	Local Area Augmentation System is a safety-critical navigation system intended to complement WAAS.

Table 3: Current ATM Applications and Descriptions

Future ATM Applications	Description
CPDLC Services	Controller-Pilot Data Link Communications (CPDLC) services replace voice communications for clearances between controller and aircraft with digital messages.
ATC Clearance (ACL)	ACL service provides the mechanism to request and receive clearances, instructions, and notifications.
Departure Clearance (DCL)	DCL service provides automated assistance for the request and delivery of departure information & clearance.
ATC Communication Management (ACM)	ACM service provides automated assistance to pilots and controllers for conducting transfer of all ATC communications (both voice and data).
Data Link Taxi Clearance (D-TAXI)	D-TAXI service provides automated assistance to controllers and pilots to perform communication exchanges during ground movement operations.
Common Trajectory Coordination (CONTAC)	COTRAC service provides a mechanism to establish and agree trajectory contracts between pilots and controllers in real-time.
ATC Microphone Check (AMC)	AMC service provides a one-way uplink alternative to voice communications for contacting aircraft via data link, in the event that a “stuck microphone” blocks the voice channel.
Automatic Downlink of Airborne Parameters (ADAP) Services	ADAP services include Flight Plan Consistency (FLIPCY), Flight Path Intent (FLIPINT), Pilot Preferences Downlink (PPD) and System Access Parameters (SAP).
D-FIS	Data Link Flight Information Services, including D-OTIS, D-RVR, D-SIGMET, D-ATIS and D-FLUP.
D-OTIS	Data Link Operational Terminal Information Service.
D-RVR	Data Link Runway Visual Range
D-SIGMET	Data Link Significant Meteorological Information
D-ATIS	Data Link Automatic Terminal Information Service

D-FLUP	Data Link Flight Update Service
DLL	Data Link Logon is the Data Initiation Capability service that allows automatic logon and contact with the system.
D-SIG	Data Link Surface Information and Guidance service delivers current, static graphical airport map to flight crew.
Traffic and Surveillance Services	These services include Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Service – Broadcast (TIS-B).

Table 4: Future ATM Applications and Descriptions

Current AOC Applications	Description
Cockpit Voice Operation	Flight crew-to-company voice services and flight crew-to-flight crew voice communications.
Airport/Ramp Area Operations	Support services that interact with pilot, cabinet crew and aircraft in order to turn the aircraft around at the gate.
Out Off On In (OOOI)	Movement service messages, including Out, Off, On, In report data that is automatically routed to the AOC Movement Control System.
NOTAM	Notice to Airmen Request/Notice to Airmen service delivers ATIS data that includes any immediate NOTAMs available.
Weather Request/Weather	Weather Request includes flight crew request for airport weather. Weather reports include METARs and TAFs.
Position Report	Automatic downlink of position during climb, cruise and descent positions of flight.
Flight Status	Reporting flight status (such as malfunction reports to maintenance).
Engine Performance Reports	Reporting Aircraft Condition Monitoring System (engine and systems) via automatic downlink and on request.
Flight Plan Transfer	Providing the operators with the ability to request and receive the AOC-developed flight plan for comparison to that assigned by ATC and for loading into avionics.
Loadsheet Request/Transfer	Load sheet and cargo information uplinked to cockpit automatically or upon request.
Flight Log Transfer	Delivering next flight assignment, estimated time of departure & gate information.
Gate and Connecting Flight Status	Manual and automatic uplink of connecting flights, ETD, and gate before landing.

Table 5: Current AOC Applications and Descriptions

Future AOC Applications	Description
Graphical Weather Information	Weather information sent to the aircraft in the form that is suitable for graphical displays in the cockpit (e.g., vector graphics).
Online Technical Trouble Shooting	Allowing airline ground maintenance staff to request information from on-board systems so that a diagnosis of problems can be performed away from the aircraft's base.
Real Time Weather Report	Automatic weather reporting in real-time.
Technical Log Book Update	Allowing the flight crew to complete the aircraft's technical log electronically and send this log to maintenance base.
Cabin Log Book Transfer	Allowing the cabin crew to complete the aircraft's cabin equipment log electronically and send this log to the AOC.
Online Documentation Transfer	Replacing many of the paper documents currently being required to be carried in the cockpit (e.g., Aircraft Manual and AICs).
Software Loading	Allowing new versions of software to be uploaded the aircraft systems.

Table 6: Future AOC Applications and Descriptions

Parameter	Value
Information Unit Size (uplink/downlink)	(1800 / 304) bits
Occurrence (uplink/downlink)	(1.25 / 2.25) msg/flt
Required Response or Delay Time	5 min
Estimated bandwidth required	1,200 bps
Precedence	None
Integrity Required (Undetected Error Rate)	$< 10^{-6}$
Availability	95 - 98%
Encryption	No
Authentication	No
Communication links used	VHF voice / ACARS
Source/Destination	Cockpit/ATC

Table 7: An Example of PDC Communications Characteristics

The third category is the Airline Administrative Communication (AAC), which pertains to the airline to aircraft messaging applications that are related to the routine administration of what can be defined as cabinet crew operations. There are presently only a few data link messages that are within this category and may by FCC licensing be transmitted on the current air-to ground data link. The following list includes such applications:

- Airlines Gate Connection Information
- Medical Assistance Requests
- Crew Schedule and Lodging Information
- Miscellaneous Free Text Crew Information
- Passenger lists
- Aircraft Catering
- Baggage handling
- Aircraft fueling
- Lost and found
- In-flight Assistance
- Duty Free Sales, i.e. purchases in the air, e.g. liquor, headphones

In some cases, these applications are performed using the airline company voice channels as described under AOC.

The data communications requirements are identical to those stated for AOC. The communications characteristics of AAC are shown in Table 8.

Parameter	Value
Information Unit Size	Messages < 256 bytes. Multi-block messages $< 3,000$ bytes
Occurrence	20 - 30 messages per flight segment
Required Response or Delay Time	< 1 min delivery. Reject messages > 5 min old
Estimated bandwidth required	VHF system - 1,200 bps. Satellite system - approx. 10,000 bps
Precedence	None
Integrity Required (Undetected Error Rate)	10^{-6} to 10^{-7}
Availability	95 - 98%
Encryption	No
Authentication	No
Communication links used	
Source/Destination	

Table 8: AAC Communications Characteristics

Finally, some Airport Operation Communications are expected to make use of the surface network. Some of the anticipated users include the Port Authority, Department of Public Safety, and the county in airport vehicles. Information for the applications for these users could not be obtained.

Surface Architectural Models and Components

In developing the architecture for the airport surface network that is scalable, reliable and flexible to support the current and future airport operations, the NASA GRC team faced with a difficult decision: which architectural model is right for the surface network? Generally, there are three types of architectural models that can be applied to any surface networks: topological, flow-based, and functional. One or all of these three types of models can be included in the Surface Reference Architecture. Topological models are based on a geographical configuration; flow-based models are based on data traffic flows; and functional models focus on one or more functions or features planned for the network. After a careful evaluation of communications systems being used today at most airports and the potential enhancement that can be made in the future for airport operations, the team decided instead to focus on the component architectures of the surface network. Component architecture is a description of how and where each function of a network is applied within that network. [5]. This is important because defining the building blocks of architecture as network functions instead of physical entities is essential to the success of the Surface Network Architecture. In order to successfully develop the surface network that will meet the operational requirements of any airports, the following major functions or components have to be defined: addressing/routing, network management, performance, and security. A brief description of each of these functions, its capability and mechanisms are shown in Table 9. For more information about these functions please see [8].

Function	Capability	Mechanisms
Addressing/ Routing	Providing robust and flexible connectivity between devices. Network devices such as IP routers, switches, SONET hubs, modems, wireless access points, firewalls, servers and end-user stations. And, connected to the core surface network, there are many diverse pieces of hardware, such as ASR-9 radar units, RTR radios, Localizers, Glide Slopes, Markers, ASDE-X, and others.	1) Addressing mechanisms for both IPv4 and IPv6 were evaluated for surface networks. Aggregation versus Classless Inter-Domain Routing (CIDR) and other considerations, including Dual Stack, 6to4 gateway, Private Addressing, Network Address Translation (NAT), Multicast, and Mobility. 2) Routing mechanisms include Routing Flows Establishment, Routing Boundaries and Routing Flows Manipulation.
Network Management	Providing network monitoring, configuration and troubleshooting for the surface network. A survey of COTS network monitoring and configuration software products were conducted. These software tools can potentially be integrated into the surface networks for monitoring and configuring.	Network management mechanisms include network management protocols (such as SNMPv3, CMIP, or CMOT), devices management and network configuration.
Performance	Providing network resources to support network performance requirements (capacity, delay, and RMA).	QoS, SLAs, and policies. QoS mechanisms include, for example, Error Detection/Correction, Adaptive Modulations, Automatic Repeat Request, Prioritization, Scheduling, Traffic Shaping/Policing, IntServ and DiffServ.
Security	Protecting surface networks and services from unauthorized access, modification, destruction, or disclosure to ensure the integrity, confidentiality, and availability of these networks and system resources and data.	Security mechanisms include firewalls, security policies and procedures, filters and access control lists. These cover, for instance, physical security and awareness, protocol and application security, authentication, encryption and decryption, network perimeter and remote security.

Table 9: Functions as Building Blocks of a Surface Network Architecture

Summary and Conclusions

This paper has summarized the results of recent NASA GRC studies regarding surface communications requirements, surface applications and architecture functions that will help design a robust and flexible network architecture to meet the current and future needs of airport operations. Based on the results of the surface network requirements assessment conducted by SAIC for NASA, we have been able to gain a better understanding of the current state of surface communications at most airports today in the United States. There is not enough information about stakeholder's expectations and needs, applications, devices and data traffic flows derived from these requirements to form the foundation upon which a scalable, reliable and flexible surface network architecture can be developed. This study, however, is a good starting point for a more comprehensive surface CNS network requirements development and analysis in future studies in which modeling and simulation of surface users, applications and network behavior may be included.

Although comprehensive data have been collected for existing and future surface applications, interoperability among these applications cannot be discerned in the context of today's airport communications or in any future trends being set by aviation and policy-making authorities. However, it is most likely that internetworking will use IPv6 as the network layer architecture standard in the future and transitioning to this standard will help achieve this interoperability, not only among surface applications but all aeronautical related applications. Encouraging news is that the FAA's current efforts involving the packet-based FAA Telecommunication Infrastructure (FTI) network and the deployment and transition to System-Wide Information Management indicate that network-centric operation is a major component of the future system. The airport surface is a crucial part of these efforts and activities, and this document is a step towards building the required networking services in this domain.

Reference

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Outline

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Background

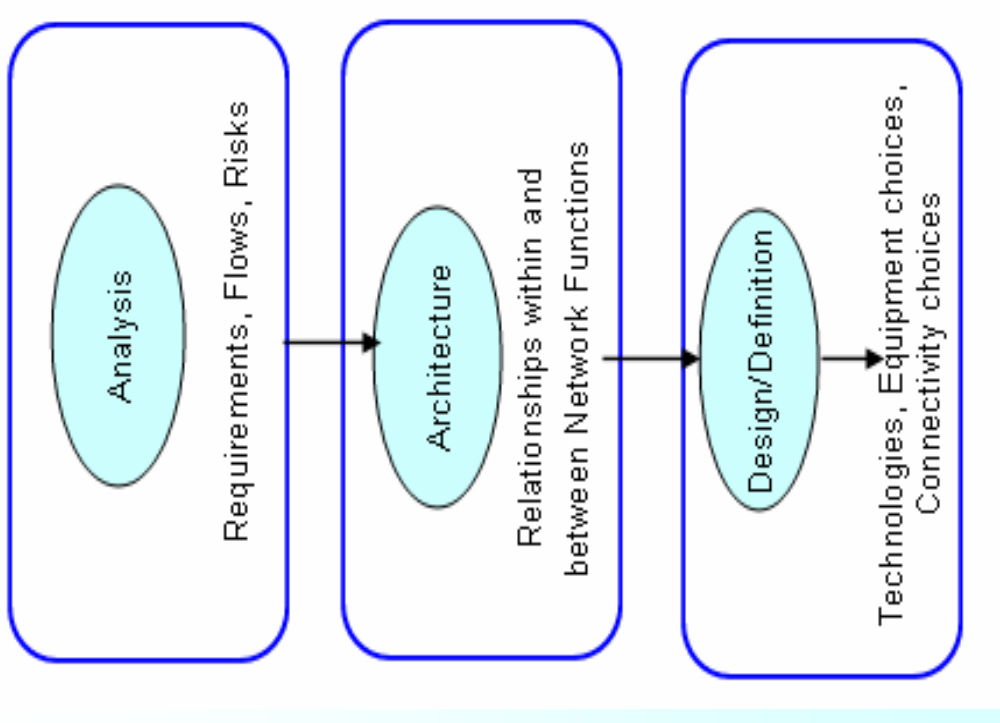
- **Project:** This research effort was supported by NASA Glenn Research Center under the ACAS/ST/SBT Project -- Surface and Terminal Area Sub-Element
- **Objective:** Assess surface communication requirements, perform surface applications analysis and define a set of architecture functions that will help design a robust and flexible *surface network architecture* to meet the current and future needs of airport operations
- **Team:** NASA and On-site Contractors:
 - ✓ T.C. Nguyen (Lead) - Analex Corporation
 - ✓ Wesley M. Eddy - Verizon Federal Network Systems
 - ✓ Steven C. Bretmersky - Cleveland State University
 - ✓ Brenda L. Ellis - NASA GRC
 - ✓ Fran Lawas-Grodek - NASA GRC

Current State of Surface Communications

- **Fragmented across multiple types of systems**
- **Built on legacy circuit-based concepts**
- **Dedicated and separate architectures**
- **Not supporting system-wide interoperability & information sharing**
- **Surface congestion is a real problem**
- **Need accurate and complete information on traffic locations & intentions, especially at night and low-visibility for managing surface traffic movement**
- **Need a systematic approach to defining a surface ICNS network architecture that is robust and flexible to meet current and future needs of airport operations, especially post-911 environment.**

Approach

- **Traditional approach to networking would not work because:**
 - **Process: too complex**
 - **Results: rarely reproducible and defensible**
 - **Focusing on capacity planning or bandwidth, while ignoring other components of network resources**
- **System Engineering (SE) Approach:**
 - **Embraced by FAA as “proven practices”**
 - **Adopted by INCOSE**
- **System methodology, as applied to networking:**
 - **Building blocks as functions of architecture, instead of physical entities**
 - **Network as part of larger system (such as the NAS)**



Information flow between network analysis, architecture and design

Surface Network Requirements Assessment

- **NASA contracted SAIC to gather surface network requirements and the results known as “Trios Report”**
 - 1. Airline operations communications systems requirements**
 - 2. FAA communication systems**
 - 3. Airport operations communications systems**
 - 4. Tenant communications systems**
 - 5. Services description and criticality evaluation**
 - 6. Current wireless systems**
 - 7. Proposed set of requirements**

1. Airline Operations Communications Systems Requirements

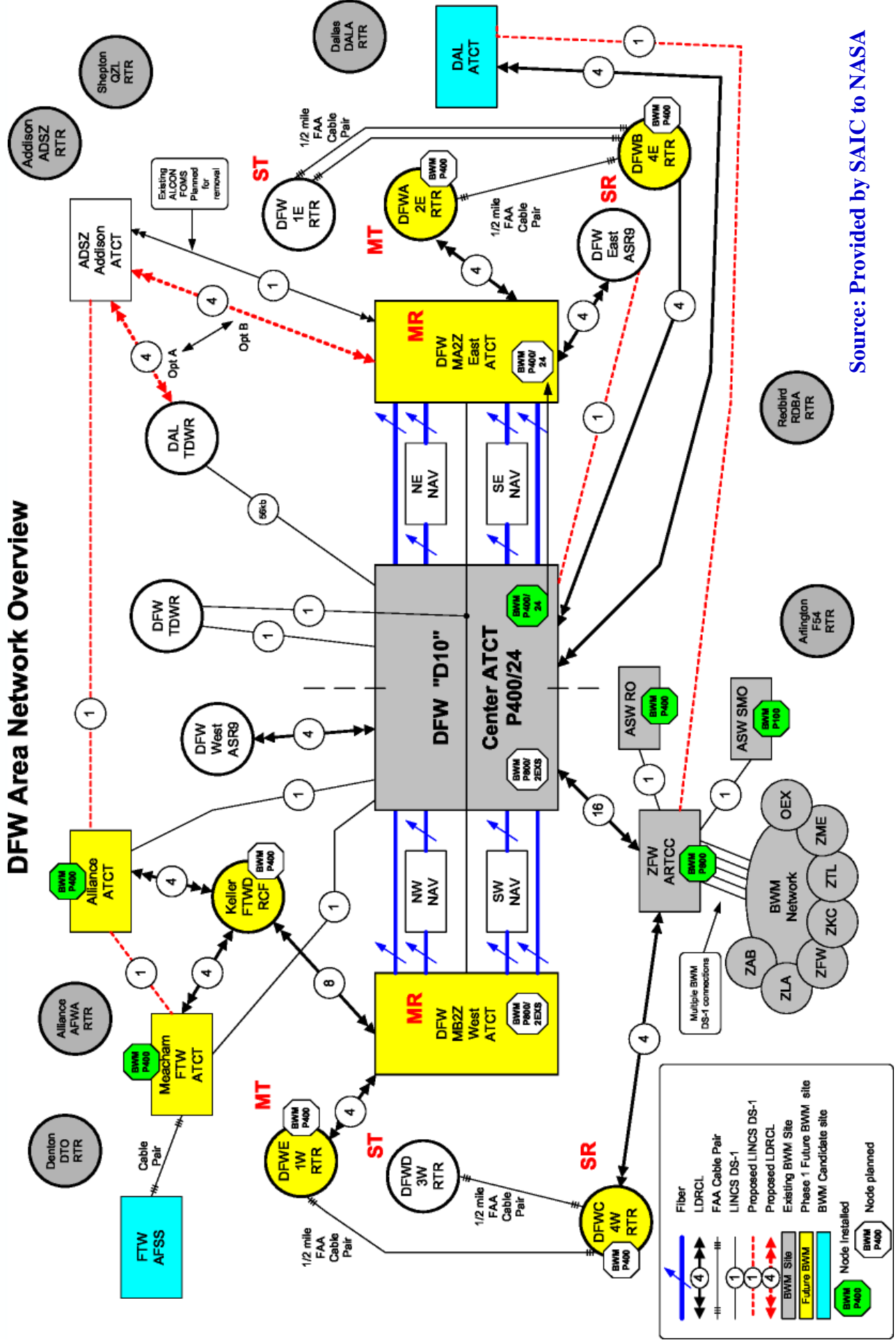
- **DFW selected for this study because:**
 - Level 12 traffic requirements by NASA was met
 - Third largest number of aircraft operation in the US
 - Home to AMR Corp, parent of American Airlines (AA) and American Eagle (AE): largest airline in the country; 73% of all aircraft at DFW
 - Estimated bandwidth requirements (voice & data) obtained:
 - AA at DFW: 45 Mbps
 - All Airlines at DFW: 58 Mbps
 - All Airlines at a typical airport: 69 Mbps (when difference in total number of airline operations between O' Hare & DFW was factored in)
 - Wireless communication for all the airlines mainly involves VHF radios for communications between the airline ramp and the pilot. For other surface activities, trunk radio systems operating in the 400 or 800 MHz ranges are used. At DFW, approximately 70 frequencies are available for airline to pilot communication and around 180 frequencies are used for airline trunk radio systems.

2. FAA Communications Systems

- **DFW was a good location for studying FAA surface communications:**
 - **Two active Air Traffic Control Towers (ATCT)**
 - **Diverse media types (copper, fiber, microwave and wireless technology spanning various FAA buildings)**
 - **Home to an ASDE-X demonstration system (using ADS-B & Multi-lateration combined with ASDE-3 radar)**
 - **Estimated bandwidth requirements for FAA communications at DFW:**
 - **23 Mbps is required between the TRACON and the two towers, and**
 - **12 Mbps is required from the TRACON to other FAA facilities on airport**
 - **For a busy airport like Chicago O'Hare, these numbers would be extrapolated to 28 Mbps and 15 Mbps respectively.**
 - **Spectrum Analysis for FAA systems revealed that around 152 frequencies are being used for ATC voice communication, radio navigation and other services.**

FAA Communications at DFW

DFW Area Network Overview



Source: Provided by SAIC to NASA

3. Airport Operations Communications Systems

- During the course of this SAIC study, U.S. DHC raised the terror alert threat to “Orange”, making it difficult to capture all DFW Airport Board (AB) communications reqs.
- However, based on network diagrams and responses to questionnaires from AB, the SAIC team was able to learn the following:
 - The network loading was estimated to be less than 10%.
 - Since the network runs at 100 Mbps in the Access Layer, any service on the airport board network cannot have a bandwidth requirement greater than 10 Mbps within the airport.
 - Communications to the outside world was close to 7 Mbps based on the infrastructure available.

Note: DFW Airport board actively uses a secure land-mobile radio system that operates in the 800 MHz range with about 32 frequencies as well as a 400 MHz radio system with 6 frequencies.

4. Tenant Communications Systems

- **Main means of communication by most airport tenants: Trunk radio systems operating in 450 MHz band**
- **Government agencies & various concessionaires use radio systems operating in 30 MHz, 150 MHz and 170 MHz ranges.**
- **Passengers: 802.11g wireless network**
- **In addition to FAA and AA/AE, DFW is home to significant UPS & Fedex cargo shipments. UPS & Fedex use wireless networks as part of their day-to-day business.**

5. Services Description & Criticality Evaluation

- **Services description & criticality of applications are determined, as follows:**
 - **For airline operations, any service interruptions that affect schedules are critical.**
 - **For FAA, all communications, navigation, and surveillance systems are critical.**
 - **Hazardous weather systems are also considered critical.**
 - **For the airport board, police, fire, and emergency as well as other airport operations in the surface movement area are considered critical.**

6. Current Surface Wireless Systems

- **Outputs of frequencies in & around DFW obtained from National Telecommunication & Information Administration (NTIA) & Aeronautical Frequency Committee (AFC) operated by ARINC, as follows:**
 - **8 mile radius, center at DFW: total of 20,000 frequency assignment records**
 - **Inside DFW airport's fence line: 4, 800 assignments.**
 - **Largest users at DFW: NEXTEL with 2,500 assignments in 800 MHz range**
 - **Users: ranging from MacDonald's to FAA to NEXTEL to ARINC.**
 - **For passenger Internet & VPN access, 802.11b currently deployed at DFW terminal area**

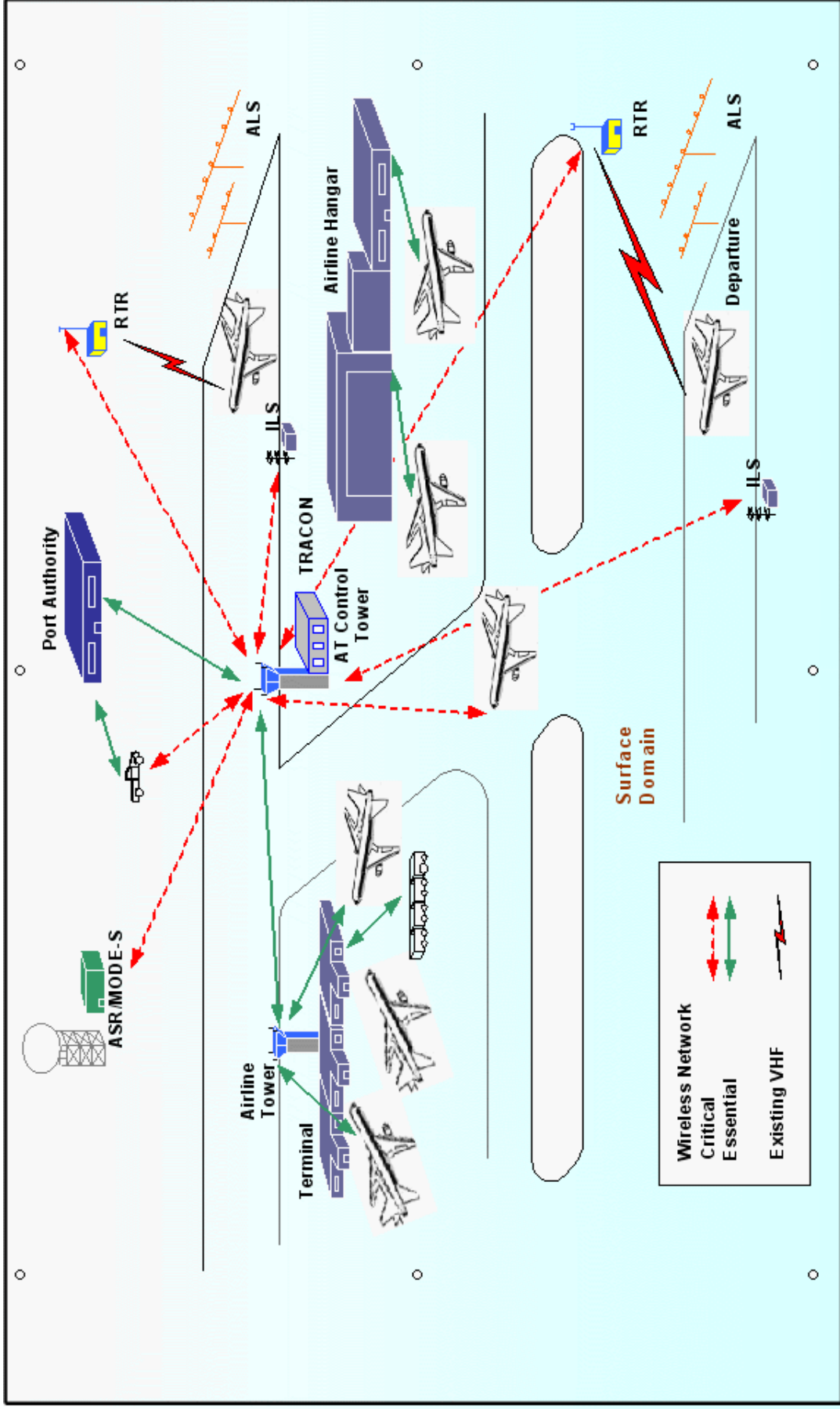
7. Proposed Set of Requirements

- The main result of requirements assessment is a set of proposed requirements for AWSN, as follows:
 - The AWSN, for Aircraft to Ground, communication shall meet the required communication technical performance of 770 ms 95% of the time and the continuity, availability and integrity numbers as specified in RTCA DO-284.
 - The AWSN shall have the following minimum data rates for each segment of the user community listed in the next slide.
 - The AWSN shall be expandable, at a minimum, to 200% of its minimum data and voice capacity requirements to support growth **(New technology may be required to meet this growth!!)**
 - The AWSN shall be capable of supporting end-to-end services that have 0.99999 availability with a six second mean-time-to-restore in accordance with FAA Order 6000.36 and the NAS-SR-1000.
 - The AWSN latency, when used as a wire-line replacement to an ATC voice and data communication site, shall not exceed 25 ms in one direction.

Estimated Data Rate for User Community

Stakeholder	Minimum Data Rate
FAA	28 Mbps (TRACON to Tower); 15 Mbps (TRACON or ATCT to RTRs, NAV AIDs, ASR-9 Radar, DBRITE, Weather Sensors, etc.)
Airlines	69 Mbps
Airport	7 Mbps for data
Passengers	54 Mbps (based on 802.11g)

Wireless Surface Network



Source: Provided by Rafael D. Apaza of FAA ATO to NASA

Surface Application Requirements Analysis

- **Major surface applications collected and categorized, as follows:**
 - 1. Air Traffic Management (ATM)**
 - 2. Aeronautical Operational Control (AOC)**
 - 3. Airline Administrative Communications (AAC)**
 - 4. Airport Operation Communications**

Current ATM Applications (1/2)

Current ATM Applications	Description
Pilot-Controller Communications	Pilot-Controller Communications includes Predeparture Clearance (PDC), Taxi Clearance and Oceanic Clearance.
Context Management (CM)	CM applications initiates and maintains data link connection between an aircraft and ground station
Airport Terminal Information Service (ATIS)	ATIS is the continuous broadcast of recorded non-control information in selected high activity terminal areas.
Notice to Airmen	Time-critical aeronautical information disseminated via the National Notice to Airmen (NOTAM) System.
Cockpit Voice	This is an ATC-related application.
Remote Transmitter/Receivers (RTR)	RTRs are responsible for carrying critical ATC radio traffic between ATCT/TRACON and pilots.
Tower Data Link System (TDLS)	TDLS is a user-friendly computer interface to support multiple concurrent airport air traffic control tower applications on one platform.
METAR	International Aviation Routine Weather Report
TWIP	Terminal Weather Information to Pilots
MDCRS	Meteorological Data Collection & Report System, which is an ATC advisory service.
LLWAS	Low-Level Wind Shear Alert System, which is used to measure wind speed and direction at remote sites around airport terminal.
AWOS	Automated Weather Observing System
ASOS	Automated Surface Observing System
ITWS	Integrated Terminal Weather System
RVR	Runway Visual Range provides real-time RVR data to FAA facilities and air carriers.

Current ATM Applications (2/2)

Surveillance	This includes Airport Surveillance Radar (ASR-9), Airport Surface Detection Equipment (ASDE-X/ASDE-3), Surface Movement Advisor, Airport Movement Area Safety System (AMASS) and Digital Bright Radar Indicator Tower Equipment (DBRITE).
NAVAIDS	Airfield Navigational Aids (NAVAIDS) are small sensors located around the airport that give aircraft information for landing and takeoff.
ILS	Instrument Landing System helps aircraft land safely on a runway and it consists of a Localizer, Glide Slope, and Markers.
MLS	Microwave Landing System
Distance Measuring Equipment	Provides distance separation measurement between an aircraft and the ground unit.
VOR	VHF Omnidirectional Ranging provides magnetic bearing information for long range navigation (up to 175 NM).
Non Directional Beacon	Provides pilots with indications of bearing to ground transmitting station.
TACAN	TACTical Air Navigation (TACAN) is a military long range navigational aid sited with or instead of a VOR.
LORAN-C	Long Range Navigation C is a civil marine radio navigation system used in coastal waters for up to 1200 miles.
WAAS	Wide Area Augmentation System is a safety-critical navigation system being developed by FAA.
LAAS	Local Area Augmentation System is a safety-critical navigation system intended to complement WAAS.

Future ATM Applications

Future ATM Applications	Description
CPDLC Services	Controller-Pilot Data Link Communications (CPDLC) services replace voice communications for clearances between controller and aircraft with digital messages.
ATC Clearance (ACL)	ACL service provides the mechanism to request and receive clearances, instructions, and notifications.
Departure Clearance (DCL)	DCL service provides automated assistance for the request and delivery of departure information & clearance.
ATC Communication Management (ACM)	ACM service provides automated assistance to pilots and controllers for conducting transfer of all ATC communications (both voice and data).
Data Link Taxi Clearance (D-TAXI)	D-TAXI service provides automated assistance to controllers and pilots to perform communication exchanges during ground movement operations.
Common Trajectory Coordination (CONTAC)	COTRAC service provides a mechanism to establish and agree trajectory contracts between pilots and controllers in real-time.
ATC Microphone Check (AMC)	AMC service provides a one-way uplink alternative to voice communications for contacting aircraft via data link, in the event that a “stuck microphone” blocks the voice channel.
Automatic Downlink of Airborne Parameters (ADAP) Services	ADAP services include Flight Plan Consistency (FLIPCY), Flight Path Intent (FLIPINT), Pilot Preferences Downlink (PPD) and System Access Parameters (SAP).
D-FIS	Data Link Flight Information Services, including D-OTIS, D-RVR, D-SIGMET, D-ATIS and D-FLUP.
D-OTIS	Data Link Operational Terminal Information Service.
D-RVR	Data Link Runway Visual Range
D-SIGMET	Data Link Significant Meteorological Information
D-ATIS	Data Link Automatic Terminal Information Service
D-FLUP	Data Link Flight Update Service
DLL	Data Link Logon is the Data Initiation Capability service that allows automatic logon and contact with the system.
D-SIG	Data Link Surface Information and Guidance service delivers current, static graphical airport map to flight crew.
Traffic and Surveillance Services	These services include Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Service – Broadcast (TIS-B).

Current AOC Applications

Current AOC Applications	Description
Cockpit Voice Operation	Flight crew-to-company voice services and flight crew-to-flight crew voice communications.
Airport/Ramp Area Operations	Support services that interact with pilot, cabin crew and aircraft in order to turn the aircraft around at the gate.
Out Off On In (OOOI)	Movement service messages, including Out, Off, On, In report data that is automatically routed to the AOC Movement Control System.
NOTAM	Notice to Airmen Request/Notice to Airmen service delivers ATIS data that includes any immediate NOTAMs available.
Weather Request/Weather	Weather Request includes flight crew request for airport weather. Weather reports include METARs and TAFs.
Position Report	Automatic downlink of position during climb, cruise and descent positions of flight.
Flight Status	Reporting flight status (such as malfunction reports to maintenance).
Engine Performance Reports	Reporting Aircraft Condition Monitoring System (engine and systems) via automatic downlink and on request.
Flight Plan Transfer	Providing the operators with the ability to request and receive the AOC-developed flight plan for comparison to that assigned by ATC and for loading into avionics.
Loadsheet Request/Transfer	Load sheet and cargo information uplinked to cockpit automatically or upon request.
Flight Log Transfer	Delivering next flight assignment, estimated time of departure & gate information.
Gate and Connecting Flight Status	Manual and automatic uplink of connecting flights, ETD, and gate before landing.

Future AOC Applications

Future AOC Applications	Description
Graphical Weather Information	Weather information sent to the aircraft in the form that is suitable for graphical displays in the cockpit (e.g., vector graphics).
Online Technical Trouble Shooting	Allowing airline ground maintenance staff to request information from on-board systems so that a diagnosis of problems can be performed away from the aircraft's base.
Real Time Weather Report	Automatic weather reporting in real-time.
Technical Log Book Update	Allowing the flight crew to complete the aircraft's technical log electronically and send this log to maintenance base.
Cabin Log Book Transfer	Allowing the cabin crew to complete the aircraft's cabin equipment log electronically and send this log to the AOC.
Online Documentation Transfer	Replacing many of the paper documents currently being required to be carried in the cockpit (e.g., Aircraft Manual and AICs).
Software Loading	Allowing new versions of software to be uploaded the aircraft systems.

Example 1: PDC Communication Characteristics (Current ATM)

Parameter	Value
Information Unit Size (uplink/downlink)	(1800 / 304) bits
Occurrence (uplink/downlink)	(1.25 / 2.25) msg/ft
Required Response or Delay Time	5 min
Estimated bandwidth required	1,200 bps
Precedence	None
Integrity Required (Undetected Error Rate)	$< 10^{-6}$
Availability	95 - 98%
Encryption	No
Authentication	No
Communication links used	VHF voice / ACARS
Source/Destination	Cockpit/ATC

Example 2: DCL Communication Characteristics (Future ATM ~ 2030)

Parameter	Value
Information Unit Size	278 bytes uplink / 249 bytes downlink
Occurrence	1 per flight airport
Required Response or Delay Time	7 sec ETE, 95%
Estimated bandwidth required	320 bps
Precedence	High
Integrity Required (Undetected Error Rate)	
Availability	
Encryption	No
Authentication	Yes
Communication links used	FCS
Source/Destination	

Airline Administrative Communication (AAC)

- AAC is pertaining to airline to aircraft messaging applications, including:
 - Airlines Gate Connection Information
 - Medical Assistance Requests
 - Crew Schedule and Lodging Information
 - Miscellaneous Free Text Crew Information
 - Passenger lists
 - Aircraft Catering
 - Baggage handling
 - Aircraft fueling
 - Lost and found
 - In-flight Assistance
 - Duty Free Sales, i.e. purchases in the air

AAC Communication Characteristics

Parameter	Value
Information Unit Size	Messages < 256 bytes Multi-block messages < 3,000 bytes
Occurrence	20 - 30 messages per flight segment
Required Response or Delay Time	< 1 min delivery Reject messages > 5 min old
Estimated bandwidth required	VHF system - 1,200 bps Satellite system - approx. 10,000 bps
Precedence	None
Integrity Required (Undetected Error Rate)	10^{-6} to 10^{-7}
Availability	95 – 98%
Encryption	No
Authentication	No
Communication links used	
Source/Destination	

Surface Architecture Functions

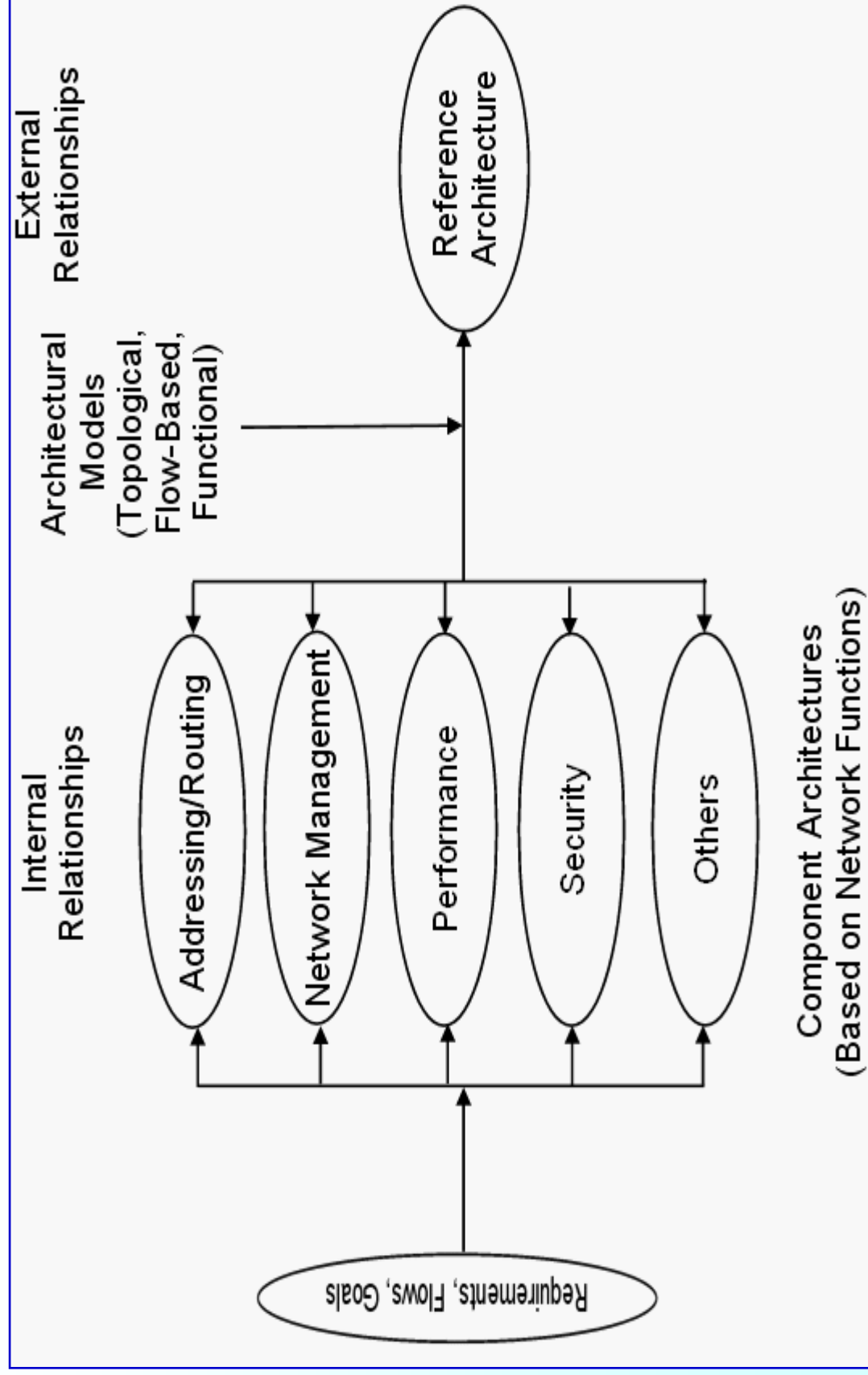
- **Defining network functions as building blocks of surface architecture instead of physical entities (e.g., routers, switches, or wireless access points)**
- **Functions or component architectures may include:**
 - **Addressing/Routing**
 - **Network Management**
 - **Performance**
 - **Security**
 - **Other (such as surface wireless infrastructure, applications services and storage)**

Capability & Mechanisms of Component Architectures

Function	Capability	Mechanisms
Addressing/ Routing	Providing robust and flexible connectivity between devices. Network devices such as IP routers, switches, SONET hubs, modems, wireless access points, firewalls, servers and end-user stations. And, connected to the core surface network, there are many diverse pieces of hardware, such as ASR-9 radar units, RTR radios, Localizers, Glide Slopes, Markers, ASDE-X, and others.	<ol style="list-style-type: none"> 1) Addressing mechanisms for both IPv4 and IP6 were evaluated for surface networks. Aggregation versus Classless Inter-Domain Routing (CIDR) and other considerations, including Dual Stack, 6to4 gateway, Private Addressing, Network Address Translation (NAT), Multicast, and Mobility. 2) Routing mechanisms include Routing Flows Establishment, Routing Boundaries and Routing Flows Manipulation.
Network Management	Providing network monitoring, configuration and troubleshooting for the surface network. A survey of COTS network monitoring and configuration software products were conducted. These software tools can potentially be integrated into the surface networks for monitoring and configuring.	Network management mechanisms include network management protocols (such as SNMPv3, CMIP, or CMOT), devices management and network configuration.
Performance	Providing network resources to support network performance requirements (capacity, delay, and RMA).	QoS, SLAs, and policies. QoS mechanisms include, for example, Error Detection/Correction, Adaptive Modulations, Automatic Repeat Request, Prioritization, Scheduling, Traffic Shaping/Policing, IntServ and DiffServ.
Security	Protecting surface networks and services from unauthorized access, modification, destruction, or disclosure to ensure the integrity, confidentiality, and availability of these networks and system resources and data.	Security mechanisms include firewalls, security policies and procedures, filters and access control lists. These cover, for instance, physical security and awareness, protocol and application security, authentication, encryption and decryption, network perimeter and remote security.

Summary

Network Architecture Process



Conclusions

- **Based on results of recent NASA studies:**
 - A better understanding of current state of surface communications has been gained.
 - Still insufficient information about stakeholder’s expectations & needs, applications, devices and data traffic flows to form the foundation upon which a robust and flexible surface architecture can be developed.
 - However, a good starting point for further research efforts.
- **Interoperability among applications cannot be discerned in context of today’s airport communications or any future trends being set by aviations & policy-making authorities.**
- **Internetworking using IPv6 help achieve interoperability.**
- **Other efforts such as packet-based FTI network, SWIM, etc.**

THE END

Thank You!