NEXT GENERATION SATELLITE SYSTEMS FOR AERONAUTICAL COMMUNICATIONS

Participating Units at U of Maryland:
NEXTOR: National Center of Excellence for Aviation Operations Research
CSHCN: Center for Satellite and Hybrid Communications Networks

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Commercial Objectives and Significance

• Objectives:
  – Hybrid ground-based/SATCOM architecture
  – Develop evolution strategy that is economically viable
  – Demonstrate benefits

• Significance:
  – Broadband communications to aircraft
  – Economic benefits to airline industry
  – Improvements in air traffic control
Types of Communication Services

- Safety Communications
  - Air Traffic Services (ATS)
    - Air Traffic Control.
    - Weather and Flight Information Services.
  - Aeronautical Operational Control (AOC)
    - Dispatch, Flight Planning, and independent company communications.
Types of Communication Services

- Non Safety Communications
  - Aeronautical Administrative Communications (AAC)
    - Cabin Provisioning, other company related non-safety communications.
  - Aeronautical Public Correspondence (APC)
    - Public Correspondence, personal communications by/for passengers.
Air/Ground Communications

- 21 ARTCCs, 3 CERAPs, 720 BUECs and 793 RCAG
- 14 FSSs, 61 AFSS and 1854 RCOs
- 175 TRACONs, 346 ATCTs, and 1422 RTRs

Terminal Facilities:
- TRACON
- Airport Traffic Control Tower (ATCT)

Remote Terminals:
- FSSs, 61 AFSS and 1854 RCOs

Automated Flight Service Station (AFSS)

Remote Communications Outlet (RCO)

Remote Transmitter/Receiver (RTR)

Air Route Traffic Control Center (ARTCC)
Remote Communications Air/Ground (RCAG)

- VHF and UHF ATC bands
- Approximately 10,000 assignments
- 50,000 (TX, RX)
- Dedicated networks for each operational environment
- Limited restoral capabilities
- No remote maintenance monitoring
Overview of En Route Air Traffic Control

- There are 21 ARTCC facilities providing ATC for the continental USA.
- Each ARTCC has control on only a portion of the airspace.
- The safe separation of the IFR aircraft in this airspace is the responsibility of the corresponding ARTCC.
- This airspace is further divided into the sectors, which have a specific radio frequency allocation for the communication between the controller of the sector and the pilots.
Spectrum Overview: Atlanta Center Airspace

...46 3-Dimensional Sectors (“Cells”)

NOTE: each sector has a frequency protected VHF assignment
Current VHF ATC Communication System

- The communication between controllers and pilots is analog and voice-only, and achieved via terrestrial remote radio stations positioned across the country.
- VHF system consists of 47,000 ground-based radios at 3,700 locations. 800 of these sites are for en-route communications.
- ATC communication is performed over the frequency bands VHF 118-136MHz (civilian), and UHF 225-400MHz (military).
Current VHF ATC Communication System

- FAA estimates that about 54 million flights will have to be handled annually by 2002.
- Current VHF system is old and the capacity is inadequate for the current increase in air traffic.
- Some disadvantages of the current VHF system are:
  - Low utilization, voice congestion,
  - Inefficient, e.g. 1 in 7 messages is a handoff.
  - High failure rates for the aging equipment, susceptibility to channel blockage.
  - Interference and lack of security.
Current Data Link ACARS

- Currently, data link is used for non-ATC air/ground communications.
- ARINC provides VHF ACARS service to over 6000 aircraft, using the 4MHz of AMS spectrum.
- ARINC also provides HFDL and SATCOM service for oceanic ATC.
**Planned Data Link Evolution**

- ARINC will be contracted to provide data link with VDL2 standard for Controller to Pilot Data Link Communications (CPDLC) starting in 1999.
- **Aeronautical Telecommunications Network (ATN)**
  - VHF A/G resources will be interconnected for efficient use of the resources and to support new capabilities such as intrinsic backup.
Digital radios and VDL3

  - By 2008 digital radios will be installed and digital voice will be in service.
  - By 2010 all high altitude en-route sectors will be using data link services.
  - NEXCOM radios will be TDMA with 4 channels (2V2D, 3V1D or 4V)
  - VDL 3 is TDMA, 25KHz channel using 10.5Kbaud rate differential 8-bit PSK; supports preemption, precedence
  - VHF A/G can support voice and data broadcast from non-FAA sources.
  - VDL 3 will deliver both ATC, and AOC data with priority, preemption, precedence.
Aeronautical Telecommunications Network (ATN)

- Point-to-point ISO/OSI packet-mode data traffic network.
- ATN will automatically route messages through best networks and data links available.
- To be fully functional, the system requires both an airborne and ground ATN router, which connects the user end systems with different A/G links and ensure reliable message delivery.
- Designed to guarantee the integrity and priority of messages
VHF TDMA System En-Route Data Link Services

- Initial Contact, Altimeter setting
- SIGMETs, PIREPs
- Weather Advisories
- Route Amendments, Traffic Advisories
- Speed Adjustments/Restrictions
- Frequency Changes/Routine Handoffs/Transfer of Radio Communications
- Traffic Management Information
- Flight Plan Amendments/Routings
Next Generation Satellite Systems

• Future medium for aeronautical communications.
• Broad feasibility study by RTCA has shown that the proposed LEO/MEO systems are feasible.
• Key considerations for the feasibility study are:
  – Compliance with AMSS SARPs.
  – Spectrum availability and interference protection.
  – Technical considerations of coverage and capacity.
  – Service interoperability
  – Economic viability.
Advantages of Next Generation Satellite Systems

- Global coverage including polar regions.
- Increased communication capacity.
- Much lower propagation delays compared to GEOs.
- Higher frequency reuse.
- The potential for universal equipage.
- Free flight.
- Economic benefits.
  - Cheaper, smaller equipment, thus smaller non-recurring and recurring costs for the airlines.
Fundamental Assumptions of Proposed Research

- Although biggest frequency congestion is at the terminal areas, the economic viability will be driven by en route communications.
- Terminal area communications capacity will be enhanced by off-loading some en-route spectrum to SATCOM.
- Hybrid ground-based/SATCOM architecture.
- Concentrate on systems issues.
Perspective of Various Players

- **FAA:**
  - reduction in cost of ground-based infrastructure
  - ability to handle increasing demand
  - new services/features

- **Airline motivator:** bottom line $$ -- benefits must justify the costs
  - revenues/benefits from “back of plane” services
  - new capabilities: oceanic/polar coverage, broadband data, ???

- **Satellite service providers:**
  - revenue potential must justify costs (usually implies bundling with passenger services)
  - aeronautical services not highest priority
Vision for NGSS Evolution for Aeronautical Communications

- **New “risky” technology**
  - Narrow-band
- **Mature, time-tested technology**
  - Broadband

- **Decreasing cost**
- **Polar & oceanic route support; links to remote terrestrial sites**
- **Primary aero comm mechanism -- free flight --**

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Near-Term: Use of NGSS as Virtual Private Lines

- Most of the remote radio sites (RCAGs and BUECs) are connected to ARTCCs via leased lines.
  - BUECs intended for use only during RCAG failures.
  - The percent of the time BUECs and the connecting leased lines are used is quite small ==> extremely low link utilization.
  - Can NGSS provide virtual private line (VPL) service to replace current leased lines?
    - A call is set up between corresponding ARTCC and the BUEC when the need arises.
    - Additional benefit of maintenance communications
Virtual Private Lines: Research Questions

- **What are the costs and benefits of such a system?**
  - In the transition to NEXCOM system, analog lines will be replaced; this provides a potentially opportune time to transition to (digital) NGSS.

- **Can NGSS provide acceptable call setup delay and call prioritization?**

- **In principle NGSS can provide high availability.** What is the cost of providing VPL service with acceptable availability?
Near-Term: Remote and Oceanic Coverage

- Currently no remote or oceanic ATC.
- Voice and data comm via HF and SATCOM.
- HF experiences high delays and is susceptible to interference.
- Inmarsat SATCOM is expensive and still experiences high delays.
- NGSS may provide low delay service with cheaper and smaller equipment.
Remote and Oceanic Coverage
Research questions

• Is such a system operationally compatible with current systems?
  – Push-to-talk, party-line, etc.

• NGSS must be compatible with ATN for data service.
  – Priority-precedence-preemption

• Capacity will be probably sufficient, due to lack of calls over the ocean.

• Interoperability of different NGSS systems
  – Can we find some operational standards that support ATC over multiple NGSS service providers?

• What are the savings for the airlines?
  – Additional flights can be accommodated; fly via shortest route.
Near-Term: Polar Coverage

- Some NGSS can provide full communication coverage for polar routes. NGSS + ADS-B provides attractive system for managing polar flights.
- Iridium, ICO, Boeing and Teledesic provide polar coverage.
- A niche use of SATCOM for NGSS providers
- More efficient routes for airlines
Polar Coverage
Research Questions

• **Operational requirements, compatibility**
  – Operational questions for oceanic coverage apply for polar coverage as well.

• **Most important question: Reliability/redundancy**
  – No other back up system.

• **What is the extent of benefits to the airlines of greatly improved polar route options?**
Medium Term: Viability of NGSS Datalink

- NGSS SATCOM is basically an additional data link, with specific characteristics.
- Initial use of NGSS SATCOM will be by transoceanic aircraft.
  - Use for ATC/ATM needs until destination terminal area is reached
  - Partition the users as equipped and non-equipped.
  - Equipped aircraft use SATCOM relieving the rest of the system.
- How much terminal and en route communication capacity is freed by different equipage penetration levels?
Medium Term: Viability of NGSS
Datalink (cont)

- Partition the information -- transfer particular information types with different communication links, i.e. SATCOM, VHF data link, VHF digital voice.
  - New data link applications, e.g. weather maps, weather advisories, are broadcast to many users and require high data rates.
  - SATCOM is a natural choice for non-time critical, high data rate information -- offloads spectrum for time critical data such as hand-offs and emergency voice.
  - Spectrum freed up for use in congested terminal areas, where voice will continue to be the primary means of communication.
Medium Term: Viability of NGSS Datalink (cont)

- What is the most appropriate partition of information among VDL-2, VDL-3, HFDL, SATCOM, and voice?
- How does the cost/bandwidth/performance of NGSS compare to alternatives?
- What requirements should be placed upon NGSS systems to provide the required performance?
Medium Term: Voice Communications and Network Compatibility

- ATC Voice Communication Based on Point-to-Point Connections
- Limited use -- primarily for over-land portion of trans-oceanic flights.
- Point-to-point connection set up to ARTCC.
- How can these connections be integrated into existing system:
  - setup delay
  - operational issues -- emulation of multi-cast connections
  - due to high setup delay, special handoff process may be needed
Control Responsibility between ATN Layer and NGSS Physical Subnet

- There will be multiple physical links and physical subnets connected to ATN layer.
- In theory ATN layer should find most efficient route to aircraft.
- What is division of responsibility between ATN layer and NGSS subnet?
Long Term: Multicast Call Problem in NGSS

• Requirement for provision of voice services
  – Some party line capability required: all airborne users in a particular “sector” should receive all information broadcast by the controller of that “sector”.
  – “sector” is used in more general sense-”community of interest”
  – These airborne users form a multicast group.
  – Each sector may be serviced by multiple spot beams, which are moving as well.
  – As the aircraft flies on it’s path, it changes spot beams as well as sectors.
  – The multicast group of a user has to be changed when it moves into a new sector.

• What are the consequences and requirements of such a system?
  – The handoff ’s should be transparent to the controllers and pilots.

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Transparent Handoffs

- Transparent handoffs should be possible both for NGSS and NEXCOM, eliminating current voice communication overhead
- Sector-to-sector handoffs within an ARTCC
  - on-site processing may be sufficient
- Handoffs between two ARTCCs
  - many cases: voice vs data, multi-cast vs unicast
  - problem may be similar to mobile wireless network handoff questions
Long Term: Terrestrial Infrastructure as Secondary Communications Mechanism

Hybrid Communication with Reduced Infrastructure

Shaded areas are zones with guaranteed terrestrial communications.
The remaining areas are serviced by SATCOM only.

Motivation: huge savings in ground infrastructure
Hybrid Communication with Reduced Infrastructure: Concepts

- Guaranteed terrestrial communication within the specified zones.
- Zones are created so as to support all major airports.
- Free flight supported by NGSS; free flight requires NGSS equipage.
Research Questions

- What is the best *reduced infrastructure*?
- What are cost savings?
- What is impact on airspace congestion?
- What equipage policies will airlines adopt in response to such an architecture?
Long Term Solution to Capacity Needs

• In the future, much higher data link capacity may be needed because of the new applications that will evolve with data link.
  – Is NGSS the most effective and cost efficient way of providing this increased capacity?

• Improvements in air traffic control by the use of NGSS.
  – Broadcast delivery of the common information
  – Better voice/data integration

• New approaches to sectorization.
Economic Justification -- FAA

- Assuming that SATCOM provides capacity enhancement and/or redundancy, how can the emerging new digital ground-based infrastructure be altered?
- Can substantial cost savings be derived?
  - What are the tradeoffs between incremental “investments” in SATCOM vs incremental investments in ground based infrastructure?
Economic Justification -- Airlines

- Will airlines be willing to equip aircraft to interface new SATCOM systems?
  - What are the benefits to airlines that justify investment?
  - Can FAA pass on potential savings to airlines?
  - Will SATCOM-primary, terrestrial-secondary be perceived as a fair, cost-effective policy that fully motivates the development of free-flight?