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

Michael Ball
Leandros Tassiulas
Özgür Erçetin

2/24/99

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

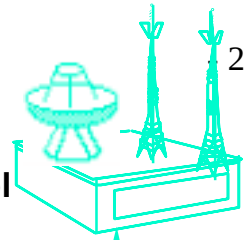
Types of Communication Services

- **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

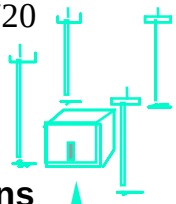
- **Non Safety Communications**
  - Aeronautical Administrative Communications (AAC)
    - Cabin Provisioning, other company related non-safety communications.
  - Aeronautical Public Correspondence (APC)
    - Public Correspondence, personal communications by/for passengers.

Air/Ground Communications



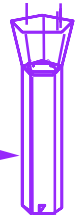
Air Route Traffic Control Center (ARTCC)

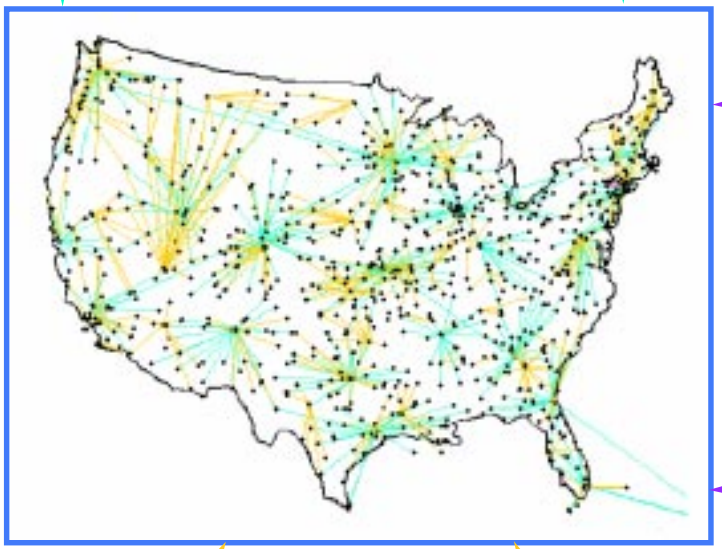
- 21 ARTCCs, 3 CERAPs, 720 BUECs and 793 RCAG



Remote Communications Air/Ground (RCAG)

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



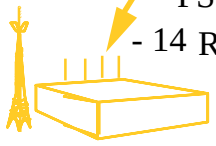


- = VHF and UHF ATC bands
- = Approximately 10,000 assignments
- = 50,000 (TX, RX)
- = Dedicated networks for each operational environment
- = Limited restoral capabilities
- = No remote maintenance monitoring

- 175 TRACONs, 346 ATCTs, and 1422 RTRs

Remote Transmitter/ Receiver (RTR)

- FSSs, 61 AFSS and 1854 - 14 RCOs



Automated Flight Service Station (AFSS)

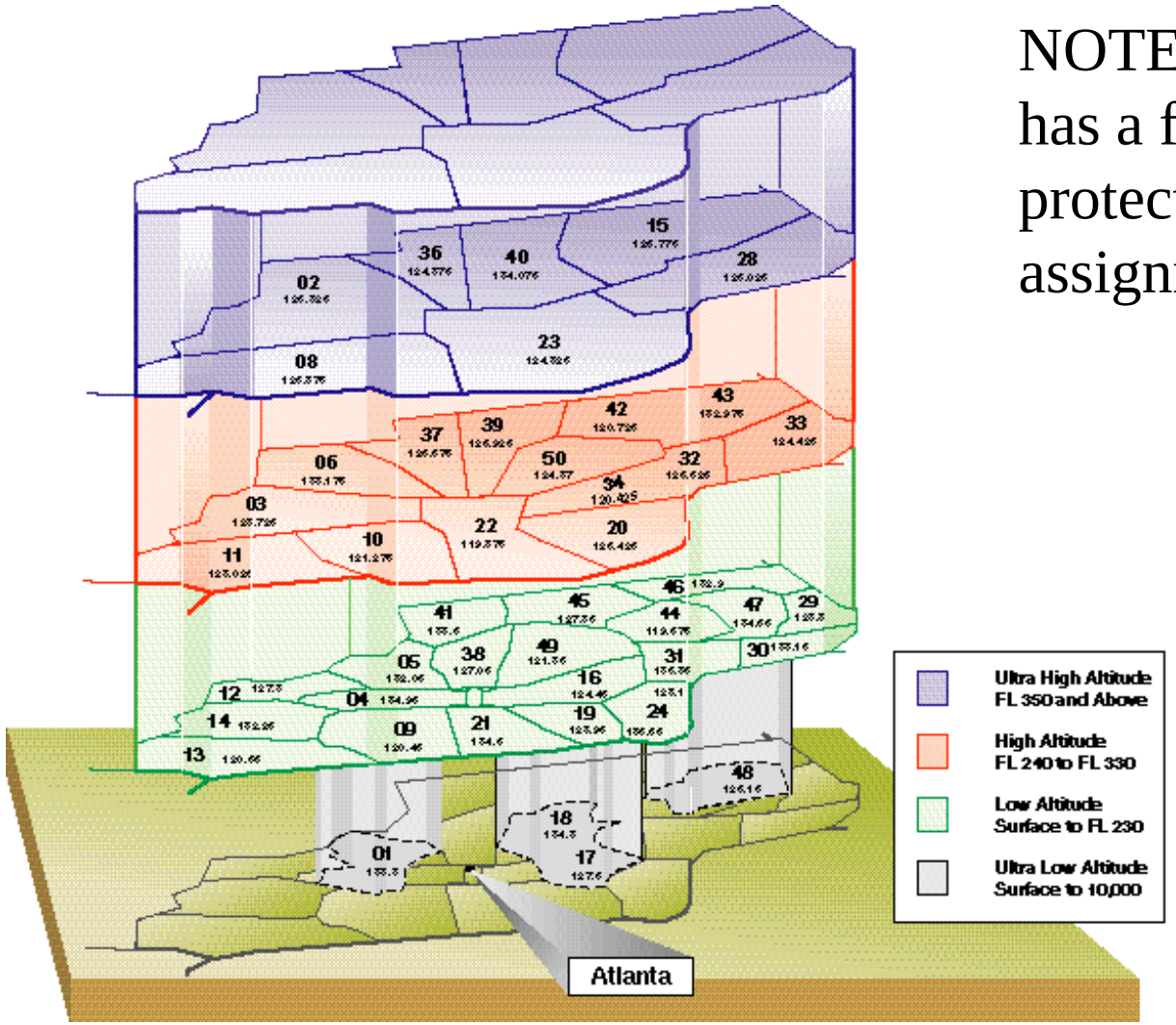
Remote Communications Outlet (RCO)

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.**
- **By 2002, FAA plans to start deployment of digital NEXCOM radios for analog voice.**
- **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 2002, FAA plans to start deployment of digital NEXCOM radios.**
  - 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 re use.**
- **The potential for universal equipage.**
- **Free flight.**
- **Economic benefits.**
  - Cheaper, smaller equipment, thus smaller non-recurring and recurring costs for the airlines.

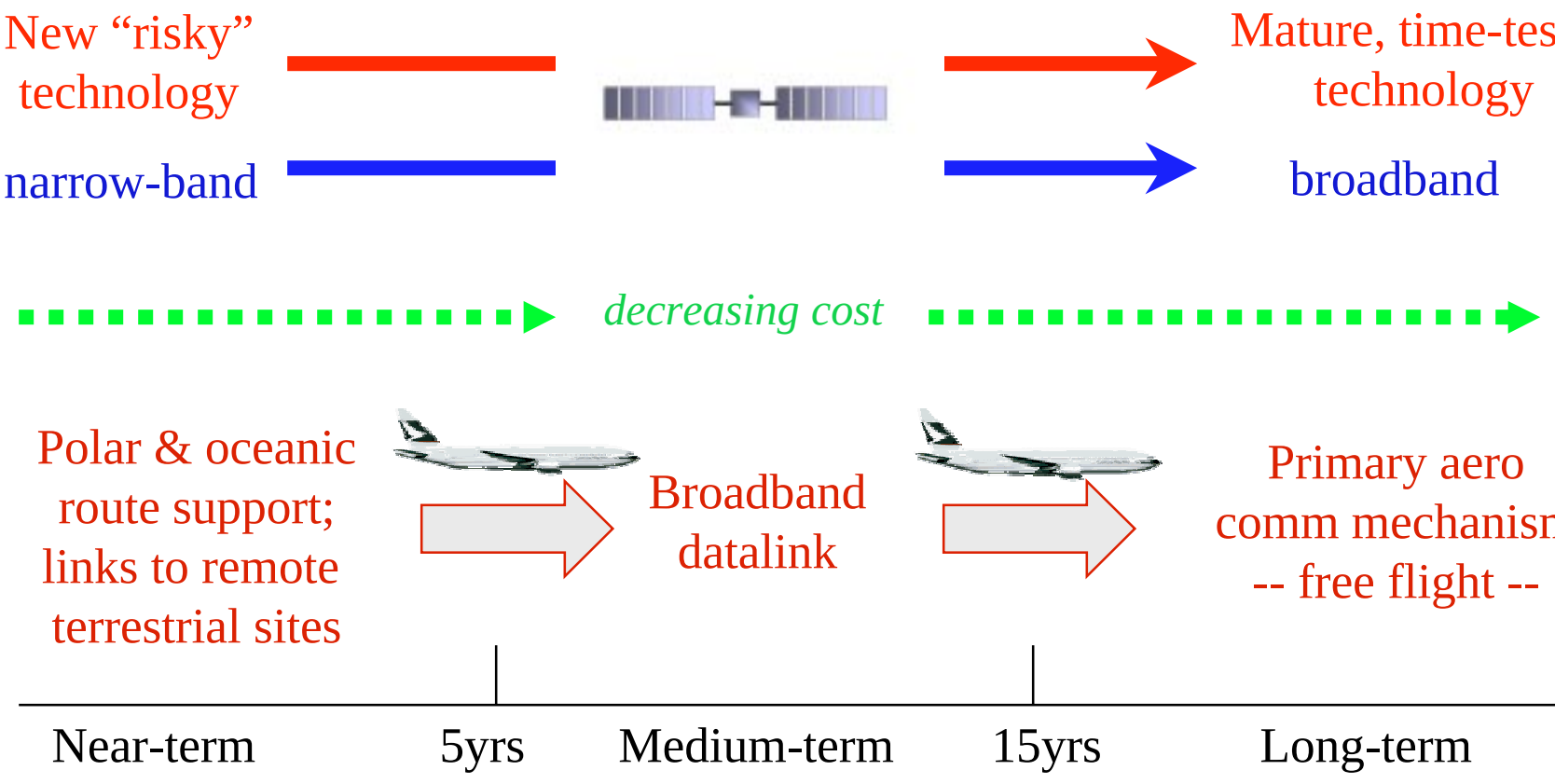
Fundamental Assumptions of Proposed Research

- **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



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

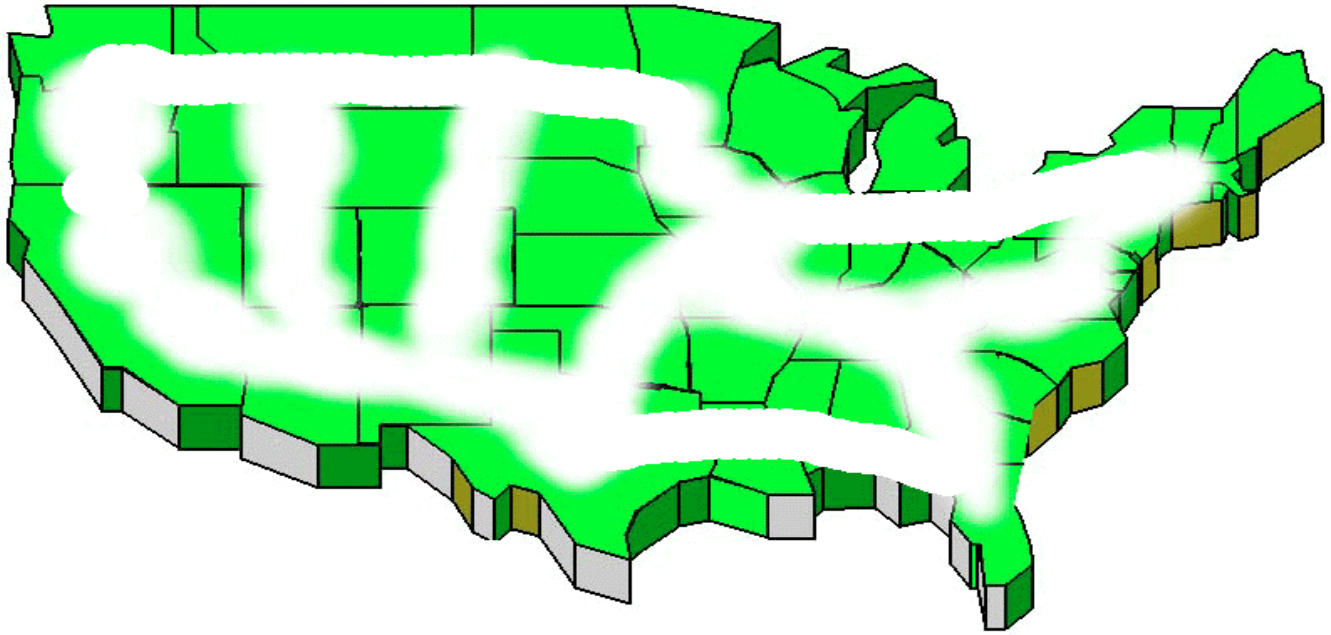
- **Requirement for provision of voice services**
  - Some party line capability required: all airborne users in a particular "sector" should receive all information broadcast by the controller of that "sector".
  - "sector" is used in more general sense-*"community of interest"*
  - These airborne users 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.

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?