Building a Global ATM Network for Ground Systems Control

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Agenda

- The Air Force Satellite Control Network (AFSCN)
- Interaction between Technical Capabilities and System-Level Design
- System Engineering by Committee
- Role of Network Abstraction in System Engineering Process
- Lessons Learned
The AFSCN

• AFSCN Elements
  – 2 Operational Control Nodes (OCNs)
  – 10 Remote Ground Facilities (RGFs)
    • world-wide presence
  – Provides satellite operators control of assets and access to telemetry data

• The Range and Communications Development Contract (RCDC)
  – Operational Switch Replacement (OSR)
    • Update Communication Segment equipment
    • Provide distributed control and monitor via an IP network
    • Remove central serial switch with network-based switching
  – AFSCN Development Integration (ADI)
    • Developed to perform Communication System integration
    • Designed long-haul communications architecture
    • Supported by Aerospace, Air Force Space Command, Air Force SMC, etc.
Key AFSCN Requirements

- **Dynamic routing of traffic**
  - Provide Satellite Operations Centers direct access to resources

- **Eliminate untoward routing**
  - Bandwidth limitations require limiting traffic flows to specific, expected paths

- **Minimize Single Points of Failure**
  - Diverse path routing
    - Must provide separate primary and additional paths to resources
  - Provide primary path robustness
    - Network can survive equipment failure on the primary path
  - Provide additional path robustness
    - Network can survive equipment failure on the additional path
AFSCN Constraints

- Use Asynchronous Transfer Mode (ATM) technology for long-haul communications
  - Provided by Defense Information Systems Agency (DISA)
- Network equipment selected before design completed
  - Cisco Catalyst 5500 switch/routers
    - Previously purchased for OSR project
  - Timeplex CX-1500 ATM-to-serial converters
- Bandwidth limitation on satellite paths
- Communication cost cannot increase with upgrade
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System Development Process

- Normal Development Phases
  - Define requirements
  - Request technical and cost proposals
    - Perform high-level system design
    - Choose implementation to fulfill design and requirements
  - Implementation
    - Design the system and individual components

- What happens when much of the implementation is chosen during the requirements definition?
  - Unsure how to factor cost into design process
  - Places constraints on the high-level design
  - Merges high-level design with the implementation design
    - Result: Technical constraints flow into high-level design
Details in the Design Process

• Considerations for high-level design
  – Robustness
  – Cost
  – Stability

• Considerations for implementation-level design
  – Type of service
  – Quality of Service (QoS) parameters
  – Link availability (always on vs. bandwidth on demand)
  – Routing hierarchy details

• Service Provider offerings
  – Current capabilities vs. expected upgrades
  – Difficult to anticipate future changes
Example: SVC versus PVP

- **Switched Virtual Circuits (SVC)** – dynamic links
  - Give up stability for robustness
    - “Wave of the future”
  - On-demand bandwidth reduces cost
  - “Cutting edge” implementation
    - ADI needed to assist DISA in defining new service offerings
    - DISA could not provide operational SVC service

- **Permanent Virtual Paths (PVP)** – dedicated links
  - Give up robustness for stability
    - “All eggs in one basket”
  - Always available for traffic – AFSCN requirement
    - QoS values will be constant for all circuits
    - “Industry standard” implementation
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System Engineering By Committee

The AFSCN Communications System

- RCDC responsible for Comm Segment
- ADI members responsible for the rest and integrating components

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Challenges of “System Engineering by Committee”

- Multiple players means multiple priorities
  - Separate priorities cause conflict
  - Without a leader, conflicts can become deadlocks
- Access to information not always equal
  - Part of this information includes factors leading to definition of priorities
- Diversity in understanding project issues
  - Most noticeable with technical concepts
Players and Priorities

• Procurement
  – Air Force Satellite Control Network Program Office (SMC/CW)
    • GFE communications developed to support OSR product with clear
      interface for easy integration
  – RCDC
    • OSR provided GFE communications necessary to meet
      specifications

• Operations
  – Space Command Operations
    • Final system can support operational needs
  – Space Command Communications
    • Final system upgrade should be maintainable

• Service Provider
  – DISA
    • Provide service while maintaining a stable network for other users
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Network Abstraction

- Network abstraction inherent in modern computer network design

- The traditional Open System Interconnection (OSI) network architecture contains 7 layers of abstraction
  - Crucial layers for network design are usually the bottom three
  - Higher layers typically have more capabilities and “intelligence”

- Legacy communications design dealt almost entirely with the physical layer

- Understanding abstract and overlay networks is a difficult task
  - Requires significant paradigm shift from the legacy era
Physical Layer

• **Primary Path**
  – Wired connection to DISA ATM fiber network for most sites
  – Serial satellite path to DISA ATM fiber network for other sites
    • Interface for AFSCN is ATM, not serial

• **Additional Path**
  – T1 architecture
    • A serial T1 connection between RGF and each OCN
  – “Broadcast” architecture
    • A serial connection from each OCN to given RGF
    • A broadcast satellite connection from given RGF to both OCNs
Abstract Layer 1 - ATM

- Permanent Virtual Paths (PVPs)
  - Dedicated Virtual Path Identifiers (VPIs) for each customer
- Switched Virtual Circuits (SVCs)
  - Virtual Channel Identifier (VCI) dynamically allocated upon call setup
- AFSCN architecture provisions a map of PVPs
  - Equipment tunnels individual SVCs through the PVPs
  - Uses CX-1500 device to convert ATM cells to and from serial streams
- Summary: Architecture allows for logically placing separate communication links (PVPs) on the same physical transmission medium.
Abstract Layer 2 – IP / PNNI

• Design uses Private Network to Network Interface (PNNI) protocol to propagate circuit paths
  – Hierarchical design uses logical nodes on physical switches
  – Logical nodes in charge of propagating paths to higher and lower levels

• Design uses Local Area Network Emulation (LANE)
  – Mechanism that emulates an IP network over an ATM architecture
  – Requires using SVC connections

• IP routing domain exists at all 12 sites
  – Uses Open Shortest Path First (OSPF) routing protocol

• Summary: Architecture overlays the ATM network map with an IP network map.
Conclusions

• The final architecture has several layers of abstraction inherent in its design
  – PVPs riding on links
  – SVCs tunneled through PVPs
  – Multiple layers within PNNI hierarchy
  – IP network overlays LANE ATM links

• Engineering a similar network requires architects to be able to work with abstractions
  – Must see the boundaries of each layer
  – Must see how changes in one layer affect the others
  – Abstractions are fundamental to understanding of complete architecture
  – Difficult adjustment for operators of legacy communication systems
Lessons Learned

• Tradeoffs in design always exist
  – Document decisions for when they will inevitably be revisited
• Define requirements in advance
  – Separate high-level design from implementation design
  – Decide up front what role cost will play in design
• Dedicate individuals and decisions to an Integrated Product Team (IPT) or keep the responsibility with one organization
• Beware of system’s dependencies on areas beyond your control (e.g. Service Providers)
• Level of technical understanding required by operations personnel and decision makers is increasing
• Competence at abstract thinking will be a requirement for future ground system designers
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