Airborne Mobile Networking Research at Boeing

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BR&T: Boeing Research & Technology

Engineering, Operations & Technology | Boeing Research & Technology

FaST | Networked Systems Technology

Boeing Commercial Airplanes (BCA)

- Headquartered in the Puget Sound region of Washington state
- 2009 revenues of $34.1 billion
- Approximately 70,000 employees
- Offering a family of airplanes and a broad portfolio of aviation services for passenger and cargo carriers worldwide
- Represent three quarters of the world’s fleet, nearly 12,000 jetliners in service
- 70 percent of Boeing commercial airplane sales outside of the United States
- Includes Commercial Avionics Services (CAS)

Boeing CTO Engineering Operations & Technology (EO&T)

- Boeing Research & Technology
- Boeing Test & Evaluation
- Enterprise Technology Strategy
- Environment, Health and Safety
- Information Technology
- Intellectual Property Management
- Enterprise Functional Excellence
- Approximately 20,000 employees

Boeing Defense, Space System (BDS)

- Headquartered in St. Louis, Mo., with global operations in 4 nations and 21 states
- 2009 revenues of $33.7 billion
- Approximately 65,000 employees
- Balanced backlog across all markets including a strong mix of development, production and support contracts
- Integrating defense, space, intelligence, and communications capability

Approximately 4,600 Employees World Wide

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DoD S&T 2020 Challenges

2020+ S&T Recommendations

Challenges

Spectrum
- JALN Waveforms concentrated in Ku-band
- Congested and co-site interference
- Single band simplifies jamming by adversary
- Limited bandwidth

Capacity and Robustness
- Accommodating ISR growth and new apps
- HCB string topology disconnected with single link or node failure
- Non-XDR waveforms lack AJ

Platform Integration & Radio Upgrade Costs
- Tight binding of radios with aircraft systems makes JALN upgrades cost prohibitive
- New waveforms can not be introduced without significant upgrades to radios & antennas

Affordability of Persistence
- High flight hour operating costs >$20K
- Large procurement costs for orbits > $250M
- Network disruptions due to aircraft handoffs and body masking

S&T Recommendations

- Integrated spectrum coordination
- Provide spectrum agility in JALN waveforms
- Move to higher frequency bands
- Use more directionality in waveforms

- Use hybrid RF/optical for air-air links
- Improve directional RF network waveforms and technology for airborne mesh
- Enhance system protection through spatial and frequency diversity

- Decouple radio upgrades from platform flight & fire control systems
- Decouple waveform processing from specific frequency bands
- Decouple radio hardware from frequency-dependent RF components on platforms

- Develop lower cost long loiter aircraft
- Factor link stability and comm relay mission performance into future aircraft designs

Source: OSD Analysis of Alternatives
Outline

Introduction

- DoD S&T 2020 Roadmap
- Dynamic Tactical Environment

Selected Technologies

1. DTCN Multi-Mode Adaptive MANET
2. RouteEx: Dynamic Routing under Cognitive Jamming
3. Open Tactical Router (Airborne Mobile Router)
4. Mobile Network Emulation
5. Airborne Network Field Demonstration
6. Aerial Mobility Models

Summary
OV-1 Dynamic Tactical Environment
Objectives

- **Infrastructure-less capability for critical traffic**
- Effective network communications support of core tactical services and OPNAV N6 Range of Warfare Command & Control (ROWC2) objectives
- Support for aircraft, surface ships, submarines, shore, TAC Mobile (maritime patrol and reconnaissance [P-3, P8, etc.])
- Ability to achieve alternative reachback in times of SATCOM availability challenges

**Enabling technology focus areas:**

- Tactical Edge Networks (e.g., JTEN, Mobile Network Highband [MNH], Joint Aerial Layer Networking [JÅLN ICD])
- Self-organizing, dynamic, mobile networking
- Enhanced Quality of Service (QoS)
- Enhanced Network Management and Control
- Increased Reliability & Availability (mission critical Information Exchange Requirements [IERs])

* This slide is an extract from a Government briefing (DTCN Program)
Why do we need DTCN?
Our environment has unique challenges not found in the commercial environment

Desire to use same network for critical and non-critical applications
- Multiple concurrent missions
- Dynamic mission phases

Multiple security domains (NIPR, SIPR, JWICS, etc.)

Mixture of radio technologies

Topology & Bandwidth Changes
- Mobility
- Interference

Continuity of operations for LOS, BLOS, & reachback under near-peer threat conditions

Source: ONR DTCN program slide
Apply a coherent traffic prioritization policy derived from Commander’s Intent

1. Radio-layer prioritization
2. Radio-Router Interface
3. Priority queuing
4. Robust IP routing for highest-priority traffic
5. Distribute highest priority traffic across all available (reliable) links
6. Segment control plane by priority
7. Red-side policing and marking to follow policy
8. Message-level prioritization
9. Application layer prioritization
10. Collect and de-conflict mission communication requirements from command hierarchy

Source: ONR DTCN program slide
Airborne Network Notional CONOPS

Airborne mobile ad-hoc networks on the tactical edge
CONOPS inputs from JAN, GIG TEN, aADNS SPAWAR PMW 160
Focus on Port Protection, ISR, GIG TEN CONOPS

• Integrated unicast routing, multicast routing, and autoconfiguration
  o supporting IPv4 and IPv6
  o Multiple interfaces

• Route redistribution issues
  o support routing policies
  o avoid unwanted transit connectivity

• Disconnection issues
• Network partition/merge

• Unicast/multicast tradeoffs
• Video streaming performance
Topic 1
Multi-Mode Adaptive Routing
Mobile Ad Hoc Network (MANET) extensions are standardized for OSPFv3 (for IPv6)
- We were directed by IETF leadership to focus MANET OSPF extensions on OSPFv3 (IPv6) only, not for IPv4

Boeing led an IETF OSPF design team, from which three proposed approaches emerged
- Boeing supports MANET Designated Routers (MDR) design approach, working with SRI (Richard Ogier’s draft) and NRL

IETF published all three as Experimental RFCs

Boeing supports an open source implementation of OSPF MDR:
- http://hipserver.mct.phantomworks.org/ietf/ospf
OSPFv3 MANET

- OSPF MANET (RFC 5614) provides efficient variant of OSPF for the tactical edge
  - OSPF MANET Interface overhead improvements (Simulation results)
  - Scales linearly with number of nodes in a dense MANET environment
  - IPv4/v6 capable

- Recent extensions in CABLE JCTD (MITLL, NRL and Boeing) enable RFC 4938 PPPoE Router-to-Radio interface
  - Cross-layer radio link quality integration

- Additional OSPF MANET maturation planned for DTCN
Reduce the number of adjacencies formed
- leverage shared flooding backbone in MDR approach

Example 100 node layout*

* Source: IETF-62 OSPF WG

Scalable to 200 nodes in a highly mobile, single broadcast domain
Tactical Network in DIL Environment

Stable Network

Unstable Network

Stable Network
Problem: Network Synchronization

No single solution works for all network environments

- Stable
- Synchronized view of the network
- Efficient network paths
- Loop-free algorithms
- e.g., OSPF, OLSR

- Unstable
- Unable to synchronize
- Inefficient to create network paths
- Flooding
- Loop-free DPD
- e.g. NRL SMF

Low Network churn High

Network churn
Adaptive Routing (Multi-Mode Routing)

Goal: Increase route robustness (availability) in dynamic networks

- **Flood in case of uncertainty**
  - Use SMF to disseminate unicast packets
  - Regular DPD, ECDS rules apply
  - Limit flooding rate for disconnected nodes (Flood requires positive Acks)

- **Use positive Acks to build on demand multipath routes**
- **Use efficient, stable routes whenever available**
Experimental Setup

Real-time Network Evaluation by CORE Emulation

Simulation Parameters:
- 30 nodes
- Random mobility
- 1200m x 1200m
- Range: 250m
- 0 – 60 mph
- 15 flows
Multi-Mode Routing Performance Results

- **30 node testbed with random mobility**
  - 1200m x 1200m, 250m range, 0-60 mph speed, 15 random flows

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Delivery Ratio</th>
<th>Overhead Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding</td>
<td>100%</td>
<td>29.16</td>
</tr>
<tr>
<td>OSPF MANET Default</td>
<td>50.3%</td>
<td>5.36</td>
</tr>
<tr>
<td>RANGE OSPF MANET</td>
<td>65.9%</td>
<td>6.01</td>
</tr>
<tr>
<td>Adaptive Routing</td>
<td>92.4%</td>
<td>5.12</td>
</tr>
</tbody>
</table>

Evaluation scenario:
- 30 nodes located in a 1200m by 1200m area, moving according to a random waypoint scenario with random speeds between 0 and 60mph.
- The wireless range of each node was set to 250m.
- Out of the 30 nodes, 15 of them were randomly selected to send data traffic, each of them to one other randomly selected node, such that every node in the network was either a sender or a receiver.
Adaptive Routing

Objective
- Blends unicast-based flooding, on-demand routing and OSPF routing without requiring tight coordination between routers.

How it works:
- Packets for which a stable OSPF path exists use the route. Otherwise, flooding and on-demand routing used to find routes.
Topic 2

RouteEx: Dynamic Routing under Cognitive Jamming
RouteEx
Dynamic Routing under Extreme (Cognitive) Jamming

- Develop and validate a novel dynamic routing scheme aimed at robust data delivery under extremely harsh DIL (disconnected, intermittent, and low bandwidth) networking conditions that include RF interferences created by intentional, covert and cognitive jammers.
Why Protocol-Aware Cognitive Jammer?

- **What is Protocol-Aware Cognitive Jammer (PACJAM)?**
  
  Based on the intimate understanding of standardized MANET protocols, it targets critical messages of the protocols at performance-sensitive time scales, i.e., control packets updating topological information generated by individual network nodes or periodic packets to learn the topology or link status.

- **Emerging wideband transceiver-based cognitive radios with powerful COTS signal processing chips make it affordable for adversaries to build COMINT-capable cognitive jammers at low cost.**
  
  - GNU/USRP open source software defined radio (SDR)

- **PACJAM vs. Dynamic Spectrum Access (DSA) Cognitive Jammer**
  
  - PACJ attacks NET layer while DSA CJ concerns MAC layer
  - PACJ will be much more difficult to detect because it can easily mimic DIL environment (whereas DSA CJ must mimic primary user)
  - PACJ can cause considerable damage on routing performance even with very low duty-cycle activities.

**MANET must address Emerging PACJ Threats seriously!**
Topic 3

Airborne Mobile Router
(Open Tactical Router)
Open Tactical Router (Boeing Mobile Router)

- A software-based IP router, interoperable with COTS routers, containing advanced protocols tailored to the tactical edge and challenging wireless environments

- High performance CPU
- Interfaces: Many
  - PC104+, Ethernet, mini-PCI, PCMCIA, USB, Serial
- Operating System: Linux
- Unicast routing: Many
- MANET: OSPFv3 MANET
  - Topology reduction
  - Adjacency reduction
  - Address families
  - Route redistribution
  - Cross-layer extensions
- Multicast routing: SMF
  - Uses reduced relay set from OSPFv3
- Autoconfiguration
  - Address - IPv4 MLA & global
  - OSPF Quagga autoconfiguration
- Airborne platform (e.g., UAV)
Testbed developed to integrate and demonstrate proposed techniques:

- **¼ Scale Extra 300S acrobatic RC airframes**
  - Weight: 21 lbs (23 lbs with fuel)
    - Up to ~25 lbs w/Comm payload
  - Wingspan: 80 inches
  - Length: 72 inches
  - Cruising speed: 20-30 m/s (44-67 mph)
- **Piccolo Autopilot**
  - GPS and Pressure Data (1 Hz)
  - IMU Data (20 Hz)
- **500 MHz AMD Geode PC104**
  - Real-time control algorithms
- **Illinois Reliability and Security Engine**
  - Implemented in Leon 3 processor
    (hardware: FPGA with Xilinx Virtex II Pro)
UAV Payload

- Batteries
- Fuel Tank
- PC104 Bay
- Throt. Servo. Tach. Board
- Empty Bay
- Piccolo Autopilot

Dimensions:
- 4 in
- 5.75 in
- 6.25 in
- 8 in
- 5.5 in
- 6 in
- 6.25 in
Open Tactical Router (OTR) Roadmap

- Autoconfiguration software integrated to first OTR release (October 2009)
- Spiral 1 OTR (2010) will contain all Self-configuring Adaptive MANET software
- Future OTR release schedule will adapt to DTCN program timetable

**Open Tactical Router (OTR)**
- **OTR Spiral 1**: -> Prior work integrated (RANGE, SAM, HIP, KSA FNC Block 2)
- **OTR Spiral 2**: -> ONR SAM products, and DTCN I Base deliverables
- **OTR Spiral 3**: -> Add DTCN II Option 1 deliverables
- **OTR Final**: -> Add DTCN II Option 2 deliverables
Topic 4

Mobile Network Emulation
Network Emulation Tool

NRL Networks and Communication Systems Branch

- Boeing developed,
- Released as open-source, hosted by NRL
- Emulates entire networks.
- Can be connected to live networks
- Can emulate additional networks.
- GUI for easily drawing topologies
- Runs real code (not a simulation)
  - real network stack
  - real protocols and applications
- Connects with real networks
  - integrate with existing hardware
  - virtually expands the size of network

Common Open Research Emulator (CORE) by Boeing

The Common Open Research Emulator (CORE) is a tool that allows you to emulate entire networks on one or more machines. You can connect these emulated networks to live networks or to additional emulated networks. CORE consists of a GUI for easily drawing topologies that drives lightweight virtual machines, and various utilities. CORE uses virtualized network stacks in a patched FreeBSD kernel, or Linux virtual machines.

Boeing’s Common Open Research Emulator (CORE) is a framework for emulating networks on commodity BSD or Linux machines.

- Efficient, scalable GUI-based drag-and-drop on canvas
- Emulates routers and hosts, and simulates links (BW, delay, errors) between them
- Network lab in a box
  - Efficient and scalable
  - Easy-to-use GUI canvas
- Runs real kernel and user-space code
  - No need to modify applications
- Connects with real networks
  - Hardware-in-the-loop
  - Distributed - connect multiple COREs
Topic 5

Robust Airborne Networking Extensions (RANGE)

Field Demonstration
Field Demonstration at Edwards AFB
Field Demo Configuration (Edward AFB)

SDT (OSPF topology)

- UAV with Ruggedized Mobile Router and Camera
- Surface-based static and mobile routers, on 802.11b channel

OSPFv3 trace

- Video (VLC)
- Ruggedized mobile router

OSPFv2 trace

- SDT route SDT topology
- Video Traffic traces
- Linux server
- Video receiver
- Projector and screen

Projector and screen
Cisco 3845
Cisco 3845
Cisco 3845
Mobile Router
Router in surface topology
Ethernet
Field Demo Displays (Edward AFB)

Control Overhead

- LS-Update
- Database Description
- LS-Ack
- Hello

UAV

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Protocols Tested

- OSPFv3 MANET Designated Routers (MDRs)
  - with Address Families extensions
- NRL Simplified Multicast Forwarding (SMF)
  - with OSPF MDR integration
- OSPFv2 (legacy unicast routing)
- PIM-Dense Mode (legacy multicast routing)
- Nack-Oriented Reliable Multicast (NORM)
- Real-Time Transport Protocol (RTP)
Topic 6

Aerial Mobility Models
Aerial Mobility Model

- Need to develop Aerial Mobility Models
  - As a foundation for high-performance airborne networks
Summary

Boeing is committed to develop key technologies in next generation tactical mobile wireless networks including:

- Dynamic Tactical Communications Network (DTCN) capability for dynamic, self-configuring and adaptive with minimal human intervention and seamlessly interwork with application prioritization
- Adaptive MANET with multi-mode routing (MMR) capability
- Open Tactical Router (OTR) derived from Boeing Mobile Router (BMR)
- CORE-based emulation of mobile network, Cyber Analysis System Tool (CAST) and security simulation capability enables large scale cyber network range experimentation. This allows for testing artificial diversity architecture for Cyber Operations
- RouteEx with a capability of interoperating Tactical MANET and Commercial Cellular technology
- iShade with a capability of dynamic adaptive routing under extreme cognitive jamming environments

Boeing understand dynamic capability needs; DoD Services and Industry can leverage Boeing’s IRAD and CRAD Technologies.