Highly-Dynamic Ad Hoc Airborne Networking for Telemetry Test and Evaluation

James P.G. Sterbenz
Abdul Jabbar, Erik Perrins, Justin Rohrer

Department of Electrical Engineering & Computer Science
Information Technology & Telecommunications Research Center
The University of Kansas

jpgs@ittc.ku.edu

http://www.ittc.ku.edu/~jpgs
http://wiki.ittc.ku.edu/resilinets

Airborne Telemetry Networking
Scenario and Environment

• Very high relative velocity
  - Mach 7 \approx 10 \text{ s contact}
  - dynamic topology

• Communication channel
  - limited spectrum
  - asymmetric links
    • data down omni
    • C&C up directional

• Multihop
  - among TAs
  - through relay nodes

16 July 2008
Airborne Telemetry Networking

Link Stability and Contact Durations

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Transmit Range [nmi]</th>
<th>Relative Velocity [knots]</th>
<th>Contact Duration [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Hop Best Case</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS – TA</td>
<td>140</td>
<td>400</td>
<td>2520</td>
</tr>
<tr>
<td>TA – TA</td>
<td>15</td>
<td>800</td>
<td>135</td>
</tr>
<tr>
<td>Single-Hop Worst Case</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA – TA</td>
<td>100</td>
<td>Mach 3.5</td>
<td>300</td>
</tr>
<tr>
<td>TA – TA</td>
<td>10</td>
<td>Mach 7.0</td>
<td>15</td>
</tr>
</tbody>
</table>

- Multihop case significantly harder
  - probability of stable end-to-end path very low

Challenges to Conventional Protocols

- Transport (e.g. TCP)
  - intermittent connectivity
  - asymmetric path characteristics
  - different reliability tradeoffs
- Network (e.g. IP)
  - hierarchy: multiple devices per TA node
- Routing (e.g. MANETs)
  - significant packet loss unless update interval very small
    - resulting in unacceptable overhead
  - geolocation and trajectory can be exploited
- MAC: addressed by iNET TDM MAC
Airborne Telemetry Networking

Requirements for Interoperability

- IP-based peripherals on TAs
  - must be addressable through TmNS
  - network protocol must be IP-compatible
- TCP/UDP applications
  - receive sensing data and control TA peripherals
  - transport through TmNS must be TCP-friendly

Airborne Network Protocol Suite

Protocol Stack and Interoperability

- AeroTP: TCP-friendly transport
- AeroNP: IP-compatible forwarding
- AeroRP: routing
AeroTP
Transport Protocol Overview

- TCP-friendly transport protocol
  - pass though TCP fields needed for E2E communication
    - ports, seq#, timestamp, ECN and TCP flags
- Multiple service types
  - class (e.g. data vs. C&C) and priority
  - cross-layer AeroNP knob
- Multiple reliability modes
  - full, nearly, quasi, none (flow), none (datagram)
- Efficient flow setup
  - data overlaps control

AeroTP
Connection and Flow Management

- AeroTP is *opportunistic*: data overlaps control
  - final ACK of TCP 3WH at GW initiates AeroTP ASYN
  - data follows immediately without 3-way handshake in TmNS
  - optional ACK depending on mode; loss may retrigger ASYN
AeroTP Transfer Modes and TCP Interoperability

- Multiple reliability modes
  - full reliability: E2E ACKs using TCP semantics
  - nearly-reliable: custody transfer at GW
  - quasi-reliable: E2E FEC giving statistical reliability
  - none (flow): connection oriented best effort
  - none (datagram): connectionless best effort (UDP-like)

AeroTP Transfer Modes

- Fully-reliable: TCP ARQ semantics
  - TmNS subject to TCP ACK delay and self-clocking
AeroTP Transfer Modes

Nearly-Reliable

- Nearly reliable: GWs ACK with *custody transfer*
  - high probability of reliability but no E2E guarantees
  - TmNS independent of TCP ACK & congestion ctrl. semantics

Quasi-Reliable

- Quasi-reliable: E2E FEC or erasure coding
  - FEC or erasure coding provides statistical reliability
  - cross-layering to dynamically adjust strength
  - erasure coding may use multipath routing
AeroTP Transfer Modes

Unreliable Connection-Oriented

- Unreliable connection-oriented: TCP-compatible
  - TCP spliced at gateway, but...
  - no error control within TmNS

Unreliable Connectionless

- Unreliable connection-oriented: UDP-compatible
  - mode for passing UDP flows
  - no error control within TmNS
AeroTP
TPDU Structure (preliminary)

<table>
<thead>
<tr>
<th>source port</th>
<th>destination port</th>
<th>sequence number</th>
<th>timestamp</th>
<th>mode</th>
<th>resv</th>
<th>ECN</th>
<th>TCP flags</th>
<th>TP HEC CRC-16</th>
<th>payload CRC-32</th>
</tr>
</thead>
</table>

AeroNP
Network Protocol Overview

- IP-compatible network protocol
  - protocol id, ECN/DSCP passed
  - IP addresses mapped to MAC address and device id
  - TDM MAC used by iNET program
- Strong header check
  - permits marking of errored payloads for E2E AeroTP FEC
- Supports multiple service types and priorities
- Congestion control
  - in-band using explicit CI (congestion indicator)
  - backpressure by monitoring neighbour transmissions
- Support for broadcast and multicast
### AeroNP Packet Structure (preliminary)

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>vers</td>
<td>Protocol version number</td>
</tr>
<tr>
<td>CI</td>
<td>Class identifier</td>
</tr>
<tr>
<td>type priority</td>
<td>Protocol type and priority level</td>
</tr>
<tr>
<td>protocol</td>
<td>Protocol identifier</td>
</tr>
<tr>
<td>ECN/DSCP</td>
<td>Differentiated services code</td>
</tr>
<tr>
<td>source TA MAC addr</td>
<td>Source node's MAC address</td>
</tr>
<tr>
<td>next hop TA MAC addr</td>
<td>Next hop node's MAC address</td>
</tr>
<tr>
<td>source TA location (opt)</td>
<td>Source node's location (optional)</td>
</tr>
<tr>
<td>destination TA MAC addr</td>
<td>Destination node's MAC address</td>
</tr>
<tr>
<td>destination TA location (opt)</td>
<td>Destination node's location (optional)</td>
</tr>
<tr>
<td>length</td>
<td>Packet length</td>
</tr>
<tr>
<td>np HEC CRC-16</td>
<td>Network protocol CRC-16</td>
</tr>
<tr>
<td>source port</td>
<td>Source node's TCP port number</td>
</tr>
<tr>
<td>destination port</td>
<td>Destination node's TCP port</td>
</tr>
<tr>
<td>sequence number</td>
<td>Sequence number</td>
</tr>
<tr>
<td>timestamp</td>
<td>Timestamp</td>
</tr>
<tr>
<td>mode resv ECN TCP flags</td>
<td>Mode, reservation, ECN, TCP flags</td>
</tr>
<tr>
<td>TP HEC CRC-16</td>
<td>Transport protocol CRC-16</td>
</tr>
<tr>
<td>payload</td>
<td>Payload</td>
</tr>
<tr>
<td>payload CRC-32</td>
<td>Payload CRC-32</td>
</tr>
</tbody>
</table>

### AeroRP Routing Protocol Overview

- **Geolocation-assisted routing protocol**
  - AeroNP header carries node position when permitted
  - node location and trajectory transmitted by GS
  - nodes snoop to learn other’s location
  - multiple modes based on required stealthiness
- **Proactive with limited updates**
  - eliminates delay of reactive
  - while limiting overhead of proactive
- **Relay nodes**
  - preferred as next hop
  - GS preferentially tracks RNs
AeroRP

Geolocation Stealth Options

- Tradeoff between stealth and performance
  - AeroRP provides a range of options
    - details of which to be worked out based on iNET requirements
- Stealthiness options
  - node include state vector (position, velocity) AeroNP header
  - nodes include own position in AeroNP header
  - GS broadcasts encrypted state vectors of all nodes
  - no position information available
    - nodes exchange neighbor table on contact

AeroRP

Performance Comparison (preliminary)

- 60-node ns-2 simulation in 150x150 km²
- TA tx range = 15 nmi; \( v = [200 \, \text{knot, Mach 3.5}] \)
- CBR traffic = 200 kb/s per TA
Airborne Network Protocol Suite
Conclusions and Future Work

• This is a only a *preliminary design!*
  - with a quick-and-dirty simulation to verify some of the ideas
  - and a not-yet-complete set of requirements for higher layers
• Detailed simulation will be needed
  - simulation model of TmNS, iNET MAC, AeroNP/RP/TP
    • model will be made available to iNET community
  - evaluate proposed algorithms and mechanisms
  - performance tradeoffs and tuning
• Lab prototype based on simulation results
  - provide working code base
• Field trials