Communication Systems for Future Airborne/Spaceborne Networks

Paulo Mendes
Senior Scientist Wireless Communications
Airbus Central Research and Technology
Munich, Germany

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Raitenhaslach, Burghausen
Germany

paulo.mendes@airbus.com
http://www.paulomilheiromendes.com

These slides do not reflect the view of Airbus
The World is getting more... data-driven

It is widely recognized that the world is increasingly data-driven, cloud-based and transnational, creating an increasing demand to move large quantities of data quickly and securely around the globe.

- Data usage has drastically increased in the last 10 years
- More data created in the past two years than ever before
- 2015: barrier of 1 Zeta Byte of global traffic undertaken.
- Forecast: data demand to grow exponentially
Towards data-driven networking
The role of airborne and spaceborne networks

Airborne/Spaceborne networks:
- Aircraft within communication range connect with each other using laser links.
- Aircraft density is sufficiently high → mesh networks between aircrafts including High-altitude platform stations (HAPS), and communication satellites.
- Access to online content available via multi-hop transmission.
- Data sharing between aircraft, even without internet access.
Airborne and Spaceborne Internet
Drivers for global data services

- High Throughput
- On Board Processing
- Low Latency
- Value Added Markets

On-board routing and switching + multi-beam technology + free space optics
Airborne and Spaceborne Internet

On board processing

- Signal is demodulated, decoded, re-encoded and modulated aboard the satellite.
- On-board processing: e.g. switching packets based on MPLS or IP routing.
- In-orbit data caching may also be considered.
- Advantages: efficient channelization, routing capabilities.
- Disadvantages: more complex; use power also to process signals.

Regenerative Payloads

Software Defined Flexible Payloads

- Reprogrammable features to address dynamic markets.
- Dynamic beam shaping and tracking capabilities.
- Design for wide-area networks and dynamic traffic shaping.
- Rapid response for public protection and disaster recovery.

Example:
- Eutelsat Quantum
- Inmarsat-6

Perspective for the integration with terrestrial networks:

- Higher flexibility on resource allocation.
- Possibility to embed a 5G gNB or gNB DU into a satellite.
- SDN and NFV will significantly reduce the risk of updated orbiting systems.
Airborne and Spaceborne Internet
Latency matters

- Satellite networks:
  - The closer to earth, the less latency there is.
  - LEO satellites orbiting the earth at around 1,500km → 25 times closer than GEO satellites (36,000km) and 5 times closer than MEO satellites (8,000km)
  - Case: LEO for data networking becomes compelling, bring latency to value around 12 ms.
    → 5 ms when the satellite is in a 90 degree angle.

<table>
<thead>
<tr>
<th>Elevation angle</th>
<th>Path</th>
<th>Distance D (km)</th>
<th>Delay (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE: 10°</td>
<td>satellite - UE</td>
<td>1932.24</td>
<td>6.440</td>
</tr>
<tr>
<td></td>
<td>satellite - gateway</td>
<td>2329.01</td>
<td>7.763</td>
</tr>
<tr>
<td>GW: 5°</td>
<td>satellite - gateway</td>
<td>2329.01</td>
<td>13.672</td>
</tr>
<tr>
<td>90°</td>
<td>satellite - UE</td>
<td>600</td>
<td>1500</td>
</tr>
</tbody>
</table>

**Bent pipe satellite**

| One way delay   | Gateway-satellite_UE | 4261.2 | 14.204     |
| Round Trip Delay| Twice               | 8522.5 | 28.408     |

**Regenerative satellite**

| One way delay | Satellite - UE | 1932.24 | 6.44     |
| Round Trip Delay | Satellite-UE-Satellite | 3864.48 | 12.88    |

3GPP TR 38.811 V15.0.0 – Study for New Radio (NR) to support non terrestrial networks (Release 15)

Typical LEO attitudes on range of (600-1200) km at low elevation of (0-10)° → fraction of Earth covered = 1.69% to 7.95%.
Airborne and Spaceborne Internet
Leveraging inter-satellite links

Round Trip Time – Telesat LEO Latency vs Terrestrial Latency

Telesat LEO simulations of traffic moving over only inter-satellite links
Round-trip time at the network layer including processing latency for system and inter-satellite links.
Airborne and Spaceborne Internet
Value added markets

- Standard-based approach → LEOs, HAPS, aircrafts becoming / may become a core component in the telecommunication infrastructure.
- Integration into cellular networks will increase role in core markets such as IoT and M2M, while fulfilling the 5G Vision.

Cellular
Backhauling and Fronthauling

Government Enterprise
Secure communications

Industry 4.0
Monitoring and operating remote equipment

Connected Mobility
Connected Vehicles
Autonomous vehicles

- Security and resilience are key attributes with a ‘touchless airborne network’.
- Carrying traffic between any points on earth without touching the earth’s surface (isolated from any terrestrial infrastructure).

- Narrowband services means bi-directional communication (e.g. for firmware updates, monitoring).
- As IoT visions such as “smart cities” become more widely deployed, high performing LEO constellations will be a cost-effective way to connect devices.

- Airlines, and cruise lines are demanding for more bandwidth for consumer devices and for Internet access anywhere.
- Autonomous vehicles require frequent upgrades independently of their location.
Airborne and Spaceborne Internet Support for efficient Edge Computing

Where is the Edge?

The edge is a (set of) networked nodes where computational and storage resources may be accessed in the short time frame.

by Vodafone

Kinetic Edge micro data center operating alongside a cellular tower.

by Vapor IO

by Vodafone
Airborne and Spaceborne Internet
Support for efficient Edge Computing

**Edge Capacity: Power perspective**

Milliwatts at one end of distributed computing (devices), and gigawatts at the other (cloud).

- World's big data centres have a total power consumption of about 100GW.
- Most equipment racks use 3-5kW, but some can go to 20kW if power and cooling is available.
- Data-centers near cell towers might be 50kW container sized units (135KW – Vapor IO).
- Note: a typical macro-cell tower might have a power supply of 1-2kW.

*Rough calculation:*

*Total realistic "network edge" will account for less than 1% of total aggregate computational capability.*
Airborne and Spaceborne Internet Support for efficient Edge Computing

Mitigate the low capacity at the edge

Orchestration of a large number of edges (at base stations)

Distributed Computing

1. Receive Captured Images
2. Assign Tracking Tasks
3. Do Pose Tracking
4. Summarize Results
5. Send back for Rendering

Rely on a lower number of higher power edges (at micro data centers)
Airborne and Spaceborne Internet Support for efficient Edge Computing

Mitigate the low capacity at the edge

Higher distance between network equipment, but potentially lower processing delay

Lower distances between network equipment, but potentially higher processing delay

eNB is illustrated in three different ways depending on its interface to other network entities.

In live network test, the delay value may be easily reach 50 ms and even 100 ms.

Delay values may be in the order of 50ms, with single LEO satellite

Difference can be higher in a edge-to-cloud scenario

Latency over larger distances (>3000Km) towards cloud centers < than terrestrial fiber optics
Airborne and Spaceborne Internet Support for efficient Edge Computing

Amazon

- AWS Ground Stations: 12 parabolic antennas installed at Amazon’s global regions.
- Plus lower-cost antennas spread across other areas:
  - Allows for more connectivity and more opportunities to downlink data.
  - Repaves the playing field for sorting out edge computing problems.
- All of this is available to customers as a service, so you’re only paying for it when you’re using it.
Airborne and Spaceborne Internet Core technology

Information-Centric Networking (ICN)
- Reduces communication latency.
- Supports intermittent connectivity.
- Embedded packet authentication and robustness against DoS attacks.

Cognitive Networking
- Automation of the network operation
- Prediction of changes through context awareness.
- Developing new services meeting current/future business needs.

Software Defined Radios / Payload
- Reduces operational risks of OBP.
- Reduces product design cycles.
- Extends live expectation by accommodation of new technologies.

5G Integration (standardization)
- Integration of gNB (full or DU) in satellites.
- Handover management for mobile base stations.
- Routing/forwarding solutions for inter-gNB communications.
Airborne and Spaceborne Internet
Final thought: Space-enabled interconnection market

Idea

- Integrate Airborne/Spaceborne networks (e.g. satellite constellations) into the Internet backbone as a global point of exchange.
- Space networks (e.g. OneWeb) sell connectivity to terrestrial Internet Service Providers.

Challenges

- Suitable Interconnection models, including transit providers.
- Relative movement of satellites in different orbits → customized inter-satellite routing protocols for optimal path discovery.
- LEO connectivity is intermittent with short disconnection bursts → may be a problem if exposed to inter-domain traffic (may increase BGP stability problem).
- Bandwidth fluctuations, due to bursty Internet traffic and oscillation of satellite link capacity due to natural phenomena.
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