GSO Communications Satellite Architecture for In-Flight Broadband Connectivity

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21st Ka and Broadband Communications Conference
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Commercial In-Flight Connectivity Timeline

2001–2006
- Connexion by Boeing™
  - Exited two years after service introduction

2007–2012
- Gogo
  - Entered high-speed IFC market through Live TV acquisition
- OnAir
- GEE

2013–2015
- ViaSat
- Thales

2016+
- Inmarsat
- AT&T
- Canceled Plans 8 months after entrance announcement

Source: Avascent
Commercial In-Flight Connectivity Timeline

2014 Example WiFi Take Rates

<table>
<thead>
<tr>
<th>% of Passengers with Connected Devices</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free WiFi Take Rate</td>
<td>40%</td>
</tr>
<tr>
<td>Paid WiFi Take Rate</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>&gt;91%</td>
</tr>
</tbody>
</table>

Key: % of All Passengers Choosing to Connect

Source: Avascent
Key Design Consideration For In-Flight Connectivity via GSO Satellite

- Coverage
- Spot Beam Sizes and Number of Spot Beams
- Capacity Throughput
- Efficiency
- Satellite Payload Architecture
  - Bent-pipe or Processed
- Spectrum / Frequency Bands
- Flexibility
- Conclusion
Major Commercial Airline Routes

Major Airline Alliance Routes
Coverage vs. Number and Size of Spot Beams

- As shown in the global air traffic pattern, desirable satellite broadband coverage requirement for in-flight connectivity in general is “global”
- Multiple GSO satellite (3 minimum) is required to provide a true global coverage
- System architect must balance the total coverage area and cost of satellite system, which is proportional to the number of spot beams.
  - Resource sharing between spot beams is an effective approach to achieve an efficient design
  - Integrated use of wide beams and spot beams is another way to achieve a balanced system design
  - E.g. ~0.5 to 1.0 deg beams for high density regions such as CONUS & Europe; and ~3.0 deg beams for southern oceans
Example of Satellite with Two Distinct Spot Beam Sizes

Courtesy of NBN Co. and SSL
Example of Satellite with One Spot Beam Size

Courtesy of Eutelsat
Capacity Throughput and Efficiency

- Capacity Throughput in terms of Bandwidth is:
  \[(\text{# of Beams}) \times (\text{Avg. Bandwidth per Beam})\]

- Capacity Throughput in terms of Bps/Hz is:
  \[(\text{# of Beams}) \times (\text{Avg. Bandwidth per Beam}) \times (\text{Efficiency})\]

- It is obvious that an increase in \# of Beams and/or an increase in Avg. Bandwidth per Beam will lead to higher Capacity Throughput
  
  \[(\text{Larger # of Beams also leads to higher satellite cost})\]

- Efficiency is closely related to the overall link quality, which is affected by factors such as the degree of “color” reuse (frequency and polarization reuse); as well as network parameters such as coding and modulation.
In general, it is easier to close the communications link from GSO satellite to an aircraft at cruising altitude than to a consumer terminal on the ground.

A key factor is the performance of the “User” antenna installed on the aircraft and its ability to maintain performance during aircraft movement.

GoGo’s 2Ku service uses two flat-panel antennas per aircraft (above). Credit: GoGo.
Satellite Payload Architecture

- Bent-pipe Payload is ideal for STAR network

- Processed Payload with Channelizer is required for MESH network
# Commercial Satellite Frequency Bands (Typical)

<table>
<thead>
<tr>
<th>Commercial Satellite Band</th>
<th>Uplink Earth-to-Space (GHz)</th>
<th>Downlink Space-to-Earth (GHz)</th>
<th>Bandwidth Available (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-band</td>
<td>5.925 – 6.425</td>
<td>3.700 – 4.200</td>
<td>500</td>
</tr>
<tr>
<td>Ku-band</td>
<td>14.00 – 14.50</td>
<td>11.70 – 12.20</td>
<td>500</td>
</tr>
<tr>
<td>Ka-band</td>
<td>27.50 – 30.00</td>
<td>17.70 – 20.20</td>
<td>2500</td>
</tr>
<tr>
<td>Q/V-band (future)</td>
<td>~47.00 – 51.00</td>
<td>~37.00 – 40.00</td>
<td>Up to 4000</td>
</tr>
</tbody>
</table>

Note: Spectrum varies by region, extensions to standard bands may be available in certain regions. Allocated spectrum may be a combination of primary use and secondary use for satellite.
Spectrum and Frequency Bands

- Ka-band appears to be most advantageous for broadband application, including for in-flight connectivity
  - More spectrum available at Ka-band
  - Up to 5x more spectrum available at Ka-band than at Ku-band
- At Ka-band, more spot beams can be put down with higher frequency reuse, which in turn leads to higher system capacity
  - Ku-band: 2 meter antennas have 0.7-0.8 degree beams
  - Ka-band: 2 meter antennas form smaller 0.3-0.5 degree beams
- Although Ka-band has higher propagation loss (atmosphere, rain), more challenging amplifiers, and tighter design tolerance than other lower frequency bands, technologies have matured over recent years that these disadvantages have been overcome.
- Further expansion to higher frequency bands such as Q/V-band is expected in the future
Resource Allocation Flexibility

- One of the key characteristics of in-flight connectivity by Satellite is the desire to allocate satellite resources to match the changing air traffic pattern.

- As shown in the subsequent charts, air traffic density and movement varies over a 24-hour period.
  - Continental air traffic and Trans-oceanic demand changes over the course of a day.
  - This results in the desire to offer flexible satellite resources allocation to match the varying demand.

- Examples of resource allocation flexibility:
  - Multiple-Port Amplifier (MPA) for power to beam allocation flexibility.
  - Switchable filters or digital channelizer for bandwidth and channel routing flexibility.
Global Air Traffic Pattern (~18:00 PT)
**SS-TDMA (Ka-band) switching between user beam pairs (Forward output section shown only)**

Note: This concept can be implemented with more conventional TDMA switch assembly at IF frequency with additional hardware such as up- and down-converters, more filters, and possibly MPA.
Characteristics of Next Generation HTS Satellite Solution

- More Reflectors
- More Thermal Capacity
- More EIRP
- Shorter Schedule
- Higher Dissipation per Thermal kg
- Lower Mass/transponder
- Improved Pointing
- Larger Apertures
- More Payload Accommodation
- Higher Payload Density Packaging
- Cost: Less $/Bit
- Less $/Transponder
- More Capacity Gbps
- More Flexibility
- Flight Heritage
- More Payload
Broadband Satellites by SSL

- First Ka-band spot beam satellite 1980
- Over 50 Ka-band satellites/payloads
- Increasing payload throughput and capacity
- Delivered spot beams and spectrum
- Delivered capacity beyond requirements
Conclusion

• GSO Satellite System is ideal for In-Flight Connectivity, especially for trans-oceanic services

• Satellite based broadband network is also suitable for Maritime Vessel, Oil & Gas sectors

• A GSO Satellite network can be designed and optimized for Mobile Connectivity in general
THANK YOU FOR YOUR ATTENTION