Driving Technology Needs for HTS Systems

AIAA ICSSC COLLOQUIUM
High Throughput Satellite (HTS) Broadband Opportunities: Orbits, Architectures, Spectrum, Interference and Markets

By Peter Garland, Trieste, Italy
16 October 2017
Definition of HTS

- Many interpretations
- Is it just a marketing term?
- My definition

  “SatCom response to the lowering of price per bit of competitive terrestrial systems”

- Includes both HTS GEO satellites and HTS LEO constellations
- Includes fixed and mobile terminal support
- Growing yardstick of HTS is based on cost per bit
- However, not all bits are equal
  - Military vs Commercial
  - Consumer fixed vs Mobile
  - Traffic carrying vs Overhead

There is no standard definition of HTS
Major Issues Facing HTS systems

• Spectrum
  – Ku Vs Ka Band
  – Coordination
    ▪ GEO-LEO
    ▪ LEO - LEO

• Gateway & Feeder Link limitations
  – V Band and Optical Gateways

• Connectivity
  – Bent pipe/Channelizers/Regeneration

• Flexibility of Traffic Distribution
  – Beamforming/Multi Port Amplifiers

• Total User Proposition
  – Ground Terminals/Volume/Cost

• Raw Capacity vs Useable Capacity

Huge Technology Challenges – Some common to GEO-LEO, some unique to either GEO or LEO
The Cost per Bit Equation
The cost per bit equation

• Simplified cost per bit equation:

\[
\text{Cost per bit ($/b)} \propto \frac{\text{Capex}()}{(\text{Raw Capacity}(b) \times \text{Billable ratio})}
\]

Raw Capacity – Determined by Power & Bandwidth available
Billable Ratio – Useable Capacity/ Raw Capacity - Determined by architecture/design fit against traffic distribution/profile

• Reducing the cost per bit entails a combination of the following:

1. Reducing the **cost** of the system for a given Raw Capacity
   - Several **cost reduction** activities are ongoing.
     - Launchers
     - Satellite Production Methods
     - Reduction in Gateway/Feeder Link costs
     - Low cost terminals/volume production

2. Increasing **flexibility** to improve the billable ratio
   - **Flexibility is very much tied to architectures and technology**
     - Flexibility in a single satellite
     - Flexibility in a constellation architecture (including orbit design).
Increasing Raw Capacity
Increasing Raw Capacity - Antennas

- Very high antenna gains with high frequency reuse (HTS and VHTS systems)
  - Affordable large reflectors (4-6 m class)
  - Large feed clusters
    - Low-mass, compact feed chains
    - Planar array implementation (active and/or passive)
Increasing Raw Capacity - Payloads

• Large number of beams
  – Beamformers: Digital, Array Fed reflectors, Direct Radiating arrays suitable to the orbit.
• High Frequency reuse
  – Reuse of 1 with Co-polar Interference reduction (C/I)
• Efficient RF power delivery to Beams (DC conversion efficiency and low losses)
  – High Efficiency Integrated GaN SSPAs linearized if needed.
    ▪ Mount SSPAs close to the feeds in order to minimize output losses.
      ♦ Packaging/Thermal management challenge
    ▪ Maintain efficiency over reasonable dynamic range
    ▪ Ability to turn on/off dynamically in order to save power
      ♦ Compatible with Beam hopping
• Large amount of Bandwidth
  – Use all available spectrum for users
  – Gateways use Q/V or Optical links
Increasing Raw Capacity – Spacecraft Platform

- Increase power generation / thermal management
- Minimize non-payload mass and volume
- Improved Stability and Pointing to handle multiple beams
• Ground + Satellite system optimization
  – Ground and satellite segments should be optimized as one
  – Adaptive spectrally efficient waveforms such as DVB-S2X with greater range and granularity of modulation/coding schemes
  – Interference cancellation in the forward path, supported by DVB-S2X, could achieve full (2 color) frequency reuse between beams, or at least significantly improve the 3 or 4 color C/I

• Gateways & Feeder Links
  – Implement V Band or Optical Gateways
    ▪ Releases Ka Band spectrum for user segment
  – On Board Regeneration
    ▪ Allows rate and mod/code translation on return link to better match user and feeder links to suitable mod/code
    ▪ Saves feeder link power and spectrum
Increasing Billable Ratio
Flexibility Issues

- Actual useable capacity vs raw capacity is a neglected subject
  - Brushed under the carpet
- Market hears claims based on raw capacity
- Poor billable ratios can be caused by
  - GEO
    - Inability to move capacity from one beam to another
    - Fixed beam sizes with fixed capacity/power in each beam
    - Non ability to adapt link protocols to different terminal types/sizes and traffic profile

  **The world needs spot beam gain with global beam flexibility!!!!**

  - LEO
    - All of the above
    - Plus constellation designs that spread capacity equally over the earth

  **There is a lot of Water and Sand in the world !!!!**
Increasing Flexibility (1/2)

• **Channelizers:**
  – Offers an increase in billable capacity ratio at the expense of cost and power consumption
  – Currently compatible with <200 GHz systems
    ▪ Break point will keep increasing as technology progresses
  – Not currently compatible with VHTS systems (Tb/s) unless hybrid approach is used (only part of the spectrum is channelized)

• **On-board Digital Beamforming:**
  – Combined with a phased array or imaging system, offers a highly flexible coverage and allocation of bandwidth/power
  – This approach increases the size of the digital processor significantly for a given throughput
Increasing Flexibility (2/2)

• Phased arrays:
  – For LEO/MEO, direct radiating arrays can be interesting since they have good scanning properties, enable spatial power combination and requiring a lower gain (smaller aperture, fewer elements)
  – For GEO, direct radiating arrays not as optimal as reflector solution to produce VHTS high gain beams.
    ▪ Thousands of elements required, full spectrum for each element, all elements used for each beam.
      ✷ Very high number of elements and associated active electronics result in high cost.

• Beam hopping:
  – A high rate carrier can be time shared between beams.
  – Can be a viable alternative/addition to the channelizer but requires terminals (modems) capable of burst mode reception.
    ▪ Multiple terminal providers are currently designing or testing DVB-S2X modems with burst mode capability (superframe option)
  – Compatible with almost any traditional payload, including reflector based solutions
    ▪ Tx implementation requires TWTs with switches or SSPAs or imaging system
Some Interesting Issues Moving Forward

• Bent Pipe vs Processing
  – Power kept on board is wasted!!!!!!
  – Power kept on board creates all kinds of thermal issues!!!!
  – On board processing power will never catch up with throughput demands!!!!
  – I want access and on board processing is meant for mesh traffic!!!!!

• But
  – Is processing more suited to LEO constellations?
    ▪ Digital beam forming
    ▪ Crosslink routing to overcome ocean gateway access issues
  – Can regeneration help solve the feeder link problem?
    ▪ Match the feeder link protocol to the feeder link budget rather than the user link budget (spectrum vs power efficiency)
  – Can we lower the space qualification hurdle?
    ▪ Particularly for LEO constellations
    ▪ There is some interesting progress in the area of flight qualified DSPs
  – May need to separate the forward link and return link technologies

Will Continue to be a Hot Debate
Some Interesting Issues Moving Forward

• Solving the Feeder Link Problem
  – With multiple beams and very high throughputs the cost of gateways in a GEO HTS can be prohibitive
  – With multiple satellites in a bent pipe mega constellation the cost of gateways can also be prohibitive
    ▪ Including the issues of worldwide distribution
  – The use of Ka Band for Gateways often diminishes the spectrum available for the user link
    ▪ Reduces raw capacity

• So
  – Can we use another RF Band V/Q Band
    ▪ Spectrum is greater by not by orders of magnitude
    ▪ Spatial Diversity is mandatory
      ◦ 1 for 1 spatial diversity is still expensive
      ◦ Necessary to produce a smart gateway system on a fibre ring
        ‣ Gateways may operate in a degraded throughput mode using a more power efficient mod/code
        ‣ Not always fully on or fully off
  – If we go to all that system complexity why not try optical gateways
    ▪ Very large bandwidths
    ▪ One gateway may serve a full GEO system
    ▪ Even having 10 gateways for one operational gateway may be cost effective
    ▪ Would need a smart gateway system
    ▪ Probably need to be combined with ISLs in a mega constellation
    ▪ May allow innovative techniques for interference reduction (ground based beamforming)
    ▪ Probably needs an optical payload with optical processing
    ▪ Certainly where operator has better control of traffic landing distribution
      ◦ Military systems

Maybe not so far away as you think
Some Interesting Issues Moving Forward

• In GEO HTS systems can we use the orbit slot better
  – A limited resource
• GEO Clusters
  – Allow incremental additions to capacity/service mix
  – Can somehow allow sharing of common resource
    ▪ A feeder link satellite
  – Sometimes known as fractionated satellites
• Modular Satellites
  – Could be a single orbit platform
  – Sharing common capabilities of power and feeder link over a number of frequency bands and applications
  – A GEO antenna farm
  – Could be designed for refurbishment and upgrade
• In orbit servicing
  – Goes with modular satellites
  – Enables build in orbit
    ▪ Large antenna arrays
  – Enables upgrades
    ▪ Faster processing
    ▪ New services
  – Enables repair and maintenance

A Real Paradigm Shift
Are we on the Edge of Transformation?

- Very high speed processing and digital beam forming
- Optical ISLs and Gateway Links
- In orbit build, upgrade and maintenance
- Adaptive use of spectrum between ground and space systems
- Seamless connectivity between ground and space systems in a single network (G5?)

Over to you- It’s in your hands!!