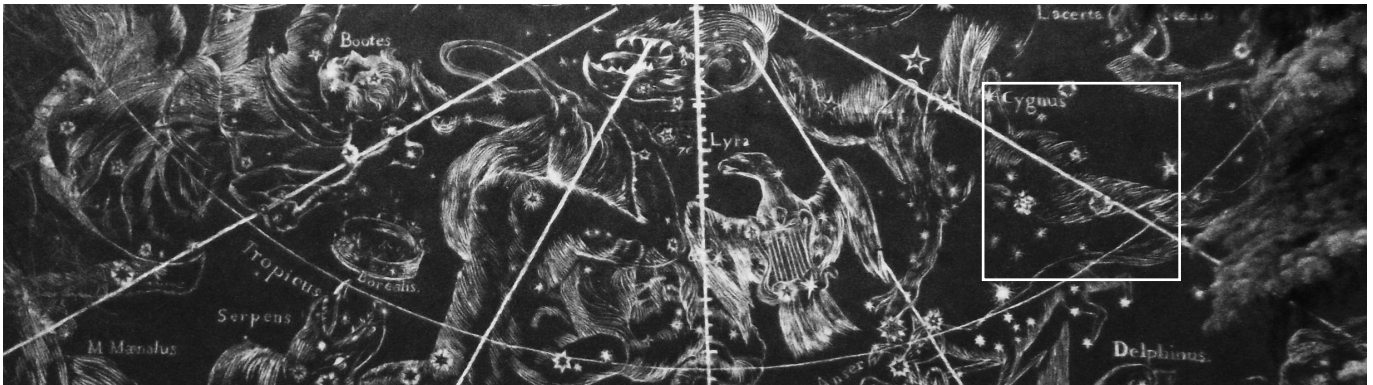


# High Throughput Satellites: Delivering future capacity needs

## Summary of white paper



Advances in satellite communications technology in recent years have led to a massive increase in throughput delivered from a raft of new 'High Throughput Satellites'. More than a dozen such satellites have been recently launched and several more will go into orbit in the coming years. These satellites support diverse user requirements and use cases – from 'connecting the unconnected' to providing secure and resilient communications to industries, SMEs and all end users. In this summary of an extended commercial and technical white paper we explore, in particular the performance tradeoffs and note the growing importance of higher frequency systems, given the significant spectrum allocations and high performance in key deployment areas.

### Overview

High throughput satellites offer a step change in bandwidth delivery to support a host of diverse customer requirements. In this white paper we explore the applications, the raft of systems launched in a variety of bands and the main tradeoffs that affect system performance, user experience and cost of service.

This viewpoint – which is the summary of an extended technical white paper, supported by Avanti Communications and Prof Michel Bousquet of ISAE – addresses four key questions for the telecoms executive who may be interested in high-throughput satellite systems (HTS):

- **User requirements:** With terrestrial networks proliferating, who is looking at such satellite systems and why?
- **Characteristics of HTS systems:** What are High Throughput Satellites and why do they "change the game"?
- **Deployments:** Where are HTS being launched, and which frequency bands do they use?
- **Performance:** What do the systems deliver technically and what tradeoffs should be considered?

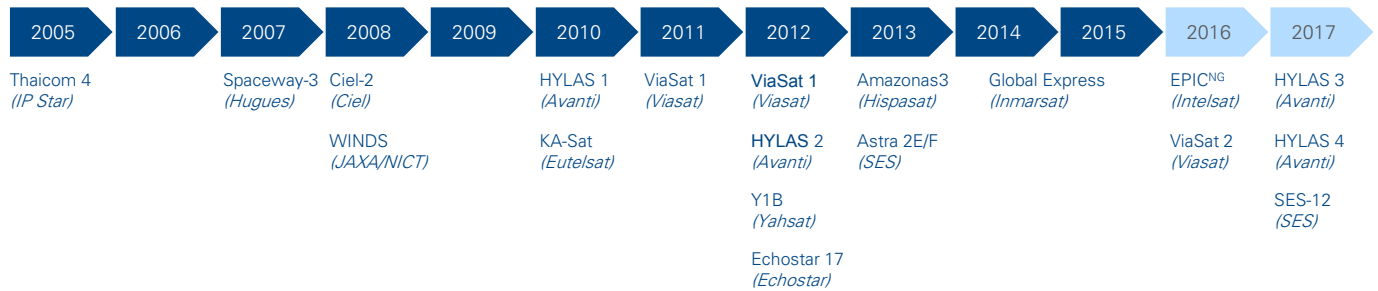
Overall, we demonstrate that High Throughput Satellites will play a key role in delivering the future capacity the customers expect, across multiple frequency bands.

### Diverse user requirements

The satellite communications industry supports a wide range of customers whose varying use case requirements as well as their actual deployment locations place exacting requirements that must be fulfilled. For example:

- **High throughput connectivity for corporates and consumers:** in areas where high quality broadband through the terrestrial infrastructure is not available, satellite technology is the most appropriate solution for providing high bitrates.  
*Example: European country side areas*
- **Basic connectivity in remote areas:** in remote areas not served with terrestrial infrastructure, satellites are the only solution for providing connectivity.  
*Example: Connectivity in schools in Sub-Saharan Africa*
- **Cellular backhaul:** providing high capacity links to support otherwise isolated base stations of terrestrial networks.  
*Example: Remote mobile base stations in Northern England*
- **Media links and resilient connections:** providing high capacity and resilience network links for industries (media, banking, lotteries, etc) with distributed sites and bespoke security requirement.  
*Example: Connection of lottery ticket retailers in North Africa*

## Major High Throughput commercial satellites launches (examples)

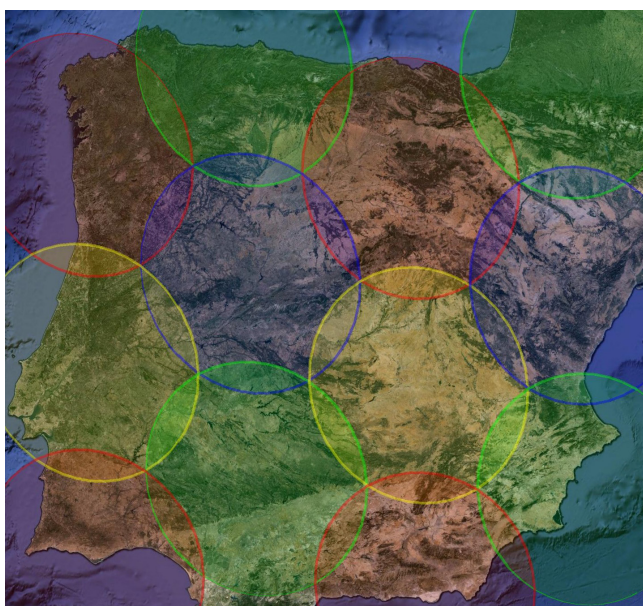


- **Satellite TV broadcasting:** supporting DTH services, with efficient delivery of one-to-many content distribution and Satellite News Gathering (SNG) services.
- **Offshore energy:** customer platforms located at sea, and not connected by seabed submarine cables.  
*Example: Production oil fields in the North Sea*
- **Onshore energy:** even when within reach of terrestrial systems, there is a need for resilient communications.  
*Example: Production gas fields in Algeria*

### Characteristics of HTS systems

**High Throughput Satellites** are a new generation of spacecraft, capable of delivering vast throughput when compared to conventional FSS, BSS and MSS satellite systems.

The one fundamental difference in the architecture of an HTS system compared to previous systems is the use of multiple 'spot beams' to cover a desired service area, rather than wide beams.



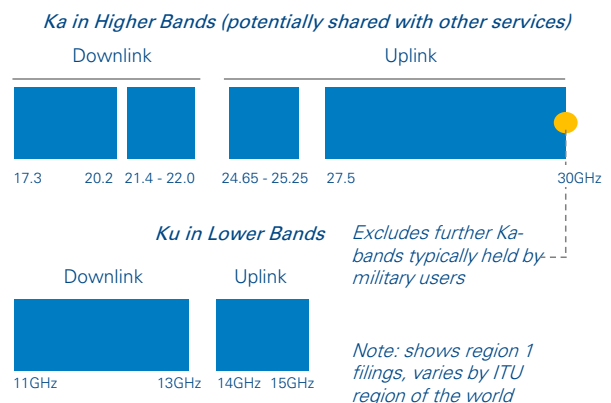
These spot beams bring a two-fold benefit:

- **Higher transmit/Receive gain:** because of its higher directivity and therefore higher gain, a narrower beam results in increased power (both transmitted and received), and therefore enables the use of smaller user terminals and permits the use of higher order modulations, thus achieving a higher rate of data transmission per unit of orbital spectrum.
- **Frequency re-use:** when a desired service area is covered by multiple spot beams, several beams can reuse the same frequency band and polarization, boosting capacity of the satellite system for a given amount of frequency band allocated to the system.

### Deployments

Many HTS systems have already been placed into orbit and already supply many Gbps of capacity, massively expanding supply since the 1990s. They can be deployed in many spectrum bands, but are mainly found in the Ku-band (lower) and the Ka-band (higher) bands. Launches will continue during 2015, most notably Intelsat EPIC<sup>NG</sup> (in Ku), Inmarsat Global Xpress and Avanti HYLAS 3 and HYLAS 4 (in Ka), and will continue for the foreseeable future, especially in the larger and somewhat less densely occupied Ka-band.

### Typical band positions for Ka and Ku satellites



## Performance

The overall performance of satellite systems depends on many factors – some determined by user requirements (terminals, operational customer locations) and some by the system overall design (physical antennas configuration, frequencies, etc.).

### For a same antenna size, Ka-band offers higher throughputs

Fundamentally, system performance is defined by the amount of orbital spectrum available and the signal quality (as measured through the radio link performance, characterized by the carrier-to-noise ratio, or  $C/N_0$ ). The most challenging part of the system is normally the user link (to/from Satellite from/to user terminal) which is driven by constraints on the characteristics of the end user terminal.

The physics and mathematics that define the overall efficiency of an HTS system, if measured via  $C/N_0$  values, are complex, but link budget calculations demonstrate the importance of spot beam design and frequency selection on system performance when taking into account the real requirements of customers.

The formulae below illustrate firstly that  $C/N_0$  is proportional to the square of the link frequency, and thus lower frequencies suffer from lower performance if a similar antenna size is used (all other things being equal). In order to compensate this, larger antennas need to be used in Ku-band systems, compared to Ka-band systems. This provides an advantage to Ka frequency systems, as they enable smaller antennas for both the satellite and the user terminals.

$$\frac{C}{N_0} \propto \frac{(D_s D_t f)^2}{L_{atm} B T}$$

$D$ : Diameter of the antennas (t: terminal, s: satellite)

$f$ : Frequency

$L_{atm}$ : Atmospheric loss

$B$ : Carrier bandwidth

$T$ : System noise temperature at receiver's side

### Ka-band enables narrower beams and therefore higher throughputs

The size of the beam depends on the inverse of the product of the satellite antenna diameter and the transmission frequency.

$$\theta_{3dB} \propto \frac{1}{f D_s}$$

$\theta_{3dB}$ : Beamwidth

As the size of the satellite antenna is constrained by the launch vehicle fairing, the use of higher frequencies lead to narrower beams:

- Ku typical achievable beamwidth: Between 0.8° and 2°
- Ka typical achievable beamwidth: Less than 0.5°

If the diameter of the satellite antenna is expressed as a function of its beamwidth in the first formula, the link performance can now be expressed as a function of the inverse proportion to the width of the beam:

$$\frac{C}{N_0} \propto \frac{D_t^2}{\theta_{3dB}^2 L_{atm} B T}$$

Therefore, narrower spot beams have higher  $C/N_0$  ratios than wider beams. The use of Ka frequencies hence enables narrower beams and higher  $C/N_0$  than Ku frequencies and therefore higher throughputs.

### Ka-band enables more reuse of frequency and therefore more capacity

Another direct effect of the narrower beams enabled by Ka frequencies is the possibility to tessellate more beams on a given area than with Ku frequency (typically with a ratio of 2 to 5). This leads to higher potential frequency reuse, even if orbital spectrum allocations are similar. Therefore the total capacity that can be delivered into a specific geography is much greater.

### Ka-band is more sensitive to severe atmospheric perturbations. However, these only occur during very limited time periods

The parameters 'Atmospheric Loss' and 'System Noise Temperature' that appear in the formula above influence HTS system performance and are partly dependent on the frequency of operation. Atmospheric losses are effectively determined by climatic conditions, and higher frequency systems are more susceptible to high intensity rain fall rates corresponding to extreme weather conditions. However these conditions occur for a small proportion of time in most regions of the world. For the majority of customer locations, the conditions offsetting the otherwise higher efficiency of a Ka-band system are likely to occur for less than 0.1% of the time. The Ka-band system offers on average higher effective throughput (for a given percentage of transponder bandwidth).

System Noise Temperature is a function of the receiving system components, i.e. the antenna and low-noise amplifier. At Ku-band the system noise temperature is typically smaller than at Ka-band, but by an amount which is less than the benefit resulting from the typical use of narrow beams at Ka-band.

Overall the  $C/N_0$  gain derived from using the higher frequency bands outweighs any disadvantages from atmospheric losses and system noise, for almost all of the time, in the majority of customer use locations. This confers spectral performance advantage to higher frequency Ka systems in many locations, except where frequent extreme weather events are experienced. Even in that case, additional mitigating strategies (such as Uplink Power Control, Adaptive Coding and Modulation, and Diverse Gateway Sites) are routine to improve the link performance and make the situation effectively transparent to the end user.

Thus potential users of future High Throughput Satellites should take into account the higher overall spectral efficiency of Ka-band systems, and consider carefully the relevance of driving parameters relative to their actual use case and deployment site.

## Key conclusions

Despite the steady growth in terrestrial networks, the expanding need for secure, resilient and configurable bandwidth at diverse customer locations, coupled with the capacity afforded by High Throughput Satellites has transformed the satellite communications industry in recent years.

Several further HTS programs are underway for launch in the coming years. These future HTS systems will further extend footprints, significantly increase the total capacity available and accelerate the trend towards more affordable and higher capacity to effectively and efficiently meet the demand for satellite data transmission.

If the choices available – in terms of geographic footprint, performance, and cost – are many, it is increasingly important for users to carefully consider their actual use case requirements. Here the Ka-band frequencies have multiple advantages over the Ku-band for high-capacity systems, in many deployment scenarios considered.

Satellite communications remains one of the most technically advanced industries, leveraging the very latest technology to continually increase the capabilities, capacity and performance delivered to its customers, where and when they need it.

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