Abstract

Since the invention by Hughes of the commercial very small aperture terminal (VSAT) and subsequent launch of the first satellite network connecting Wal-Mart stores in 1986, the satellite networking industry has evolved from a technology novelty to become an integral part of today’s mainstream telecom infrastructure—serving many millions of enterprise, government, and consumer customers around the globe. From the first VSATs weighing several kilos, supporting 9.6 kbps data rates, and operating over limited power satellites with capacities typically below 1 Gbps, the latest high-speed Internet services deliver speeds from 10 Mbps and higher to continent-wide populations, operating over powerful satellites having well over 100 Gbps capacity. In this white paper we explore the architectures and capabilities of this new generation of high-throughput satellite systems and show how they enable service delivery of an expanding world of media-rich applications—competitively, across all market sectors. This white paper showcases the experience Hughes has as the world’s largest Ka-band system operator and as the developer of a new set of technologies, known as JUPITER™, which Hughes uses as the foundation of its own Ka-band systems to support a wide range of applications and markets, including the most demanding enterprise and government applications.

The JUPITER technologies enable significant advances in several key areas including:

- **Efficient Air interface** – Enhancements to the DVB-S2 standard bring higher orders of modulation and wideband carriers which enable higher efficiencies and throughputs.

- **Advanced gateway architecture** – Very high density gateway architecture supporting over 1 Gbps capacity per rack (inclusive of all radio functionality and IP processing) featuring autonomous design and “lights out” operation whereby the gateways can be operated independent of other network elements.

- **High throughput remote terminals** – Next-generation VSAT system leveraging powerful new chipsets that enable very high data throughputs and capable of supporting many devices simultaneously.

- **Powerful value add features** – Cost-effective VNO (Virtual network operator) capabilities to enable sharing for spot beam systems, advanced QoS capabilities to differentiate various services levels including video, and sophisticated OSS (operational support system) tools that enable a large population of remote terminals to be effectively managed.

Evolution of Commercial Satellites: From Telephony to Television to Data

In April 1965 as the Cold War and space race were escalating, the Hughes-built Early Bird/Intelsat 1 geostationary satellite was launched, ushering in commercial satellite communications. Beyond carrying telephone voice and fax transmissions between North America and Europe, more significantly, Early Bird initiated the emerging larger business of satellite television, vividly demonstrated by live TV coverage of the Gemini 6 spacecraft splashdown in December 1965. For another 20 years, television carriage would be the primary mission of communication satellites—until the invention of the VSAT by Hughes engineers in 1985. Sam Walton’s decision to implement a VSAT network to connect his rural stores and distribution centers launched the satellite networking industry, and was eventually recognized by Fortune magazine as one of the 20th century’s most significant business decisions because “it gave Wal-Mart a huge informational advantage” over the competition. The satellites used at the time were optimized for television broadcast applications, covering as large an area as possible—in other words, designed for coverage versus capacity. For this reason, many of the satellite services still operating today offer the classic “CONUS” (Continental US) coverage, which enables a video broadcaster to reach the vast majority with a single transmission signal, as illustrated in Figure 1.
The first satellites operated in the C-band (4–6 GHz) spectrum and, over time, newer satellite payloads were developed for the higher frequency Ku-band (10–14 GHz), which dominated worldwide until the last decade. Driven by exploding demand for HD television and high-speed Internet access that in many regions exceeded Ku-band capacity limits, the industry moved into the much higher frequency, Ka-band (18–30 GHz). The tradeoff for coverage comes at the sacrifice of capacity, as these earlier generation satellites generally support only a few Gbps total capacity if used for data communications. Consider a typical satellite that supports a payload of 24 C-band transponders (36 MHz each) and 24 Ku-band transponders (36 MHz each). The total of 48 transponders means that the satellite supports a total of 1.7 GHz of capacity. Assuming that a 36 MHz transponder translates to about 70 Mbps of data then this 1.7 GHz of capacity would achieve a little over 3 Gbps of capacity when used for data communications.

But recently, a new class of satellites, dubbed “High Throughput Satellites” (HTS) by Northern Sky Research, has been launched. HTS satellites achieve greater capacity through the implementation of multiple spot beams such that frequency can be reused. As illustrated in Figure 2, these satellites utilize a design similar to that used by the cellular industry, whereby spot beams are separated from one another by a combination of frequency and polarization. In fact, these techniques are not new to the satellite industry and have been employed in a number of satellite designs. The difference now is the use of smaller beams which enables a greater overall number of beams and thus a higher level of frequency reuse. In the case of the Hughes SPACEWAY 3 satellite, described further in this document, a frequency reuse of 24 times was achieved whereby the 500 MHz allocated to the satellite produced an effective 12 GHz of capacity.

The EchoStar® XVII satellite with JUPITER™ high-throughput technology is another example of a high-throughput satellite design, in this case utilizing 60 spot beams, each of which is separated by a combination of frequency and polarization. Its beam layout has been combined with the earlier SPACEWAY® 3 satellite to optimize coverage over North America as illustrated in Figure 3.
Frequency reuse across multiple beams results in significant effective capacity beyond that of a CONUS-type architecture. By way of example, consider an HTS design that employs 60 spot or user beams. If each of these beams has 500 MHz of forward channel capacity and 500 MHz of return channel capacity (a typical Ka-band allocation), then the satellite is able to deliver 60 GHz of capacity throughout the footprint of these 60 beams. As can be seen, through frequency reuse, an HTS design is able to achieve considerably more GHz as compared to a conventional satellite without frequency reuse, in this particular case more than 30 times the amount of spectrum. The total cost to design, construct, and launch a satellite is roughly the same whether the satellite is optimized for capacity or coverage. For this reason, the cost per delivered bit for the HTS design is significantly lower than for a satellite optimized for coverage.

Ka-Band and Ku-Band For HTS

Many of the new HTS satellites utilize Ka-band frequencies for the simple reason that the orbital slot allocation for other bands has long been exhausted. Today, it is extremely difficult to obtain commercially viable Ku-band orbital slots from the International Telecommunication Union (ITU)—the international governing body, which tracks and allocates these orbital slots. On the other hand, Ka-band orbital slots are generally under-used. Though virtually every Ka-band slot has multiple filings, only a few of the slots have actually been used which means that it is far easier for an operator to obtain rights to a Ka-band orbital slot from the ITU. Another important benefit of Ka-band is the availability of greater amounts of spectrum versus Ku-band. While a typical Ku-band satellite might operate across 750 MHz of spectrum a Ka-band satellite might operate across 1500 MHz or more of spectrum for the gateway feeder beams alone.

Ka-band based technologies have achieved maturity to the point where the performance, reliability, and availability of Ka-band networks is comparable to Ku-band networks. This extends from the gateway radio frequency transmission (RFT) equipment, where the industry is bringing to market travelling wave tubes (TWTs) supporting output power up to 750 watts, to the high volume VSAT production incorporating state of the art gallium arsenide (GaAs) monolithic microwave integrated circuits (MMICs) to produce reliable, cost-effective, and high-performance VSAT radios operating in Ka-band.

HTS satellites are often assumed to be only Ka-band but the same design principles of smaller beams along with frequency reuse can be applied to Ku-band as well. One such example is the Intelsat 29E or “EPIC” satellite. In designing this satellite, Intelsat is able to utilize its existing Ku-band orbital slot assignment and frequencies for its spot beam architecture. Based on information from the Intelsat Web site, the first of the EPIC satellites has the following characteristics:

- Multiple spot beam of 2-degree (or less) beam width
- 160 Mbps spot beam capacity
- 40 Mbps wide beam capacity
- 25–60 Gbps of capacity

By employing 2-degree beams (rather than the the smaller spot beams of 0.4 to 0.8 degrees which are common for Ka-band satellites) and frequency reuse, Intelsat is able to design a satellite with a very wide area of coverage while still offering higher capacity relative to conventional satellites.

Different Architectures

As noted earlier, a number of different satellite architectures can be employed and optimized for data communications. Each of these has advantages and disadvantages depending on primary mission objectives.
Wide Beam Using Traditional 36–56 MHz Transponders

This traditional design, as illustrated in Figure 4, uses satellites optimized for coverage where the beam (or footprint) of the transponder covers a very large geographic area (such as Continental US). But in addition, this architecture employs a “loopback” design whereby the satellite relays all of the received signals directly back to the footprint of the transponder. With this design any station can transmit/receive in a single satellite hop to/from any other station, thereby achieving mesh connectivity.

Small Spot Beams

In designing an HTS satellite, there is a trade-off of capacity versus coverage when determining the beam sizes. A smaller beam will enable higher capacity owing to the fact that, all other things being equal, the smaller beam will have better link characteristics thereby enabling higher spectral efficiency and thus capacity. Larger beams, on the other hand, spread the RF energy across a wider geographic area thus meaning lower spectral efficiency but at the gain of covering a larger area. The high throughput EchoStar XVII/JUPITER satellite for North America utilizes small user beams of about 0.5 degrees or larger (about 300 kms in diameter). Each of these user beams are connected to a Gateway beam/station with different frequencies used for the forward and return channels. As illustrated in Figure 5, employing a spot beam architecture means that remote terminals can only receive from the Gateway station and not from other remotes. This design approach maximizes capacity since the Gateway stations can be located away from the user beams, and the Gateway beam can utilize user beam spectrum.
As illustrated in Figure 6, with this architecture a Gateway station is located within each of the Gateway beams. The Gateway station utilizes the Gateway beam to transmit the forward channel information to the various user beams. The Gateway beam actually consists of one or more subchannels, each of which is mapped to a specific user beam. The satellite breaks out the various forward channels of the feeder beam in order to deliver each of the forward channels to the appropriate user beam. The return channels are configured in a similar arrangement.

![Gateway Forward Feeder Beam](image)

**Figure 6. Forward Channel Configuration of Small Spot Beam System**

In this architecture, the limiting factor on the size of the Gateway station is the amount of feeder beam spectrum available and not the number of user beams served. It should also be noted that this architecture does not enable single-hop, site-to-site, or mesh connectivity, as the remotes are unable to see each other’s transmissions.

**Regenerative Systems**

In the examples noted above, the satellites are operated in what is known as a “bent pipe” configuration, whereby the satellite essentially acts as a relay to retransmit whatever waveform is received directly back to earth. But there also exists an architecture known as “regenerative” whereby the satellite demodulates the signals it receives and remodulates these signals for transmission back to earth. Figure 7 illustrates the differences between these approaches.

![Bent Pipe Payload versus Regenerative Payload](image)

**Figure 7. Bent Pipe Payload versus Regenerative Payload**

The Hughes SPACEWAY 3 satellite is an example of a Ka-band system that is able to deliver high throughput where its needed, owing in part to the advance phased array antenna on the spacecraft which enables dynamic allocation of power, as illustrated in Figure 8. This is in contrast to satellites that use conventional fixed direction antennas, in which case demand may exceed a given beam’s capacity or vice-versa, a fixed beam may have excess capacity beyond demand in that coverage area—both of which are detrimental to a service business case. Through this unique combination of technologies, SPACEWAY 3 is able to achieve an unprecedented level of adaptability, with the ability to:

- reconfigure beam sizes and shapes
- tune capacity for different regions
- dynamically allocate capacity per beam as the traffic needs change
The SPACEWAY 3 satellite is an early example of many of the advanced technologies used in HTS systems today, including small spot beams and frequency reuse.

**MEO Systems**

Medium earth orbit (MEO) satellite systems, whereby a constellation of satellites is established that constantly “flies over” the earth, as illustrated in Figure 9, can also be used to achieve high data capacities. The O3b system is one such example. From any one place on earth (within the northern and southern 45-degree latitude mark) the satellites will 'fly by', such that a remote station requires a tracking antenna to track the satellite as it flies across the earth. In fact, the O3b remote stations require two tracking antennas so that the remote can perform "make-before-break" decisions and ensure that connectivity can be established with the next satellite to fly over prior to the current satellite disappearing from view (as it continues its flight around the earth).
As a MEO system, the O3b satellites fly at a much lower orbit than Geostationary satellites (typically a few thousand kilometers vs 40,000 km above earth) and this lower orbit means lower latency. Thus, the O3b system promises to bring large amounts of capacity with low latency to those locations where the beams are aimed. The latency and capacity benefits of the O3b system are mitigated by the higher complexity of the remote stations, since two motorized antennas are required to ensure always-on connectivity.

**Bigger May Not Be Better**

Just because the industry can make 100+ Gbps satellites does not mean that every operator should be planning to deploy such a large capacity satellite. Of the more than 50 active Ka-band communication projects (either in orbit or planned), the majority of these systems are employing a partial payload supporting Ka-band connectivity. With this approach, satellite operators are able to incrementally add Ka-band capacity onto a satellite whose primary mission may be the traditional 36/54 MHz Ku- and C-band coverage optimized for broadcast.

A good example of one such approach is the Hispasat Amazonas 3 satellite launched in 2013. The Amazonas 3 satellite supports the following payload:

- 33 Ku-band transponders
- 19 C-band transponders
- 9 Ka-band spot beams

Assuming that these spot beams are 500 MHz each, this satellite will enable 9 GHz of capacity for the Ka-band data services alone.

A partial payload or even a dedicated Ka-band payload but with a smaller satellite mass (and thus lower capacity) may be attractive to service providers for a variety of reasons, including:

- Small geographic coverage area – perhaps the target market is one country of modest size
- Anticipated slow fill rate – the take-up in developing parts of the world may be slower than North America or Europe, thereby reducing the need for immediate deployment of a lot of capacity. In these areas it may make more sense to optimize for coverage rather than capacity
- Lower capex – the cost to implement a partial payload on a satellite will be significantly less than the cost to launch a dedicated satellite.

For these reasons and more, it is not necessarily true that “bigger is better”. In fact, “bigger is better” only when the fill rate or usage of the capacity is certain to be quickly consumed. Where market demand may be uncertain, a smaller capacity can enable an operator to ease into a market with a lower investment.

**Dedicated and Open Systems**

There are a number of different business models in practice for the new generation of high-throughput satellites. The largest, such as EchoStar XVII with JUPITER high-throughput technology, provides well over 100 Gbps of capacity over North America and operates as a dedicated system. As illustrated in Figure 10, a dedicated system is one where a single entity operates the satellite, procures the ground system, and offers the services directly and/or through one or more retail partners to end users. In this so-called ‘Mbps model’ construct, the operator is maximizing its return on investment by ultimately selling Mbps through a variety of service plans and there is limited possibility for an independent service provider to purchase satellite bandwidth alone for the purpose of offering its own services.
In order for a dedicated system to prosper, the service provider must make significant investments beyond simply the satellite and ground system. The service provider needs to have a complete Business Support System (BSS) related to running a service business, including order processing, installation scheduling, customer activation, billing, CRM, help desk, trouble-ticketing, and other business processes. In addition, and perhaps more significantly, the service provider must invest and develop a comprehensive set of distribution channels that will bring the service to the end users. This kind of infrastructure cannot be developed easily, which is why a variant on this approach is to outsource the BSS systems and sell Mbps to established retail distribution channels.

In contrast, as illustrated in Figure 11, an open high-throughput satellite system is one where the satellite operator sells bandwidth capacity to individual operators (so-called ‘MHz model’) of capacity to individual operators who take on the responsibility to procure the ground systems, develop the BSS, and then sell Mbps and develop the BSS so that they can sell Mbps service plans through their distribution channels or directly to end users. This type of model is potentially attractive to a satellite operator, as it reduces risk associated with the service business and lets the satellite operator focus on its core competency of managing spacecraft.

Hughes strongly believes that open systems will prosper in many regions of the world as satellite operators launch partial HTS payloads that will be made available to operators on a per MHz basis. The JUPITER technology that enables Hughes to achieve over 1 Gbps total processing (inclusive of all IP processing) in a single rack can also be effectively used to provision small amount of capacity over many beams and in a small amount of rack space. The JUPITER technology air interface enables bi-directional high throughput and the JUPITER technology remote terminals have the fastest throughputs of any VSAT terminal on the market. With a rich set of enterprise-grade features, these systems can be used for a wide range of applications demanding the highest SLAs and QoS capabilities.

There are many variants possible in the business models, including the implementation of a virtual network operator (VNO). The term VNO originates from the cellular industry and describes a reseller of a given operator’s facilities to provide its own branded service. In this sense, the operator is “virtual” because the reseller does not need to invest directly in its own
facility. The benefit to the VNO is minimal capex investment, while the benefit to the facilities operator is maximum use of its facilities. Unfortunately, in the recent past the satellite industry has misused the term VNO and it has come to mean essentially teleports hosting network equipment; but the satellite “VNO” has still been required to purchase its own network hardware and, more significantly, purchase dedicated space segment.

With the introduction of high-throughput systems, it is likely that the satellite industry will more closely follow the mobile industry, whereby the VNO does not own facilities but instead leases Mbps so that it can provide Mbps services with minimal investment. The reason for this is that a typical high-throughput satellite will have many beams and the capex to provision a small amount of MHz on each of the beams may be cost-prohibitive for a smaller VNO.

**Optimizing a Satellite Design**

The traditional approach to developing a satellite communications system has been for a service provider to lease existing satellite capacity from a satellite operator. In other words, the satellite has already been designed, built, and launched. The service provider must make use of the capacity that is already in orbit so the design choices by the service provider are limited to what ground system to use. But designing a high-throughput satellite requires a great deal of knowledge about the market that will be addressed, as well as significant consideration of a number of key design factors, including:

- Location and size of the user beams
- Amount of spectrum per user beam
- Contiguous or noncontiguous coverage
- Location and spectrum for Gateway stations

How best to design a high-throughput satellite is well beyond the scope of this paper, but the experience of Hughes is that the highest possible capacity and performance can be achieved when the design of the ground system is done concurrently with the design of the satellite. This enables the satellite operator to take full advantage of crucial aspects of the ground system, such as carrier performance for the forward and return channels.

**Evolution of Ground Systems**

Since the first network for Wal-Mart, VSATs have evolved in very significant ways. Figure 12 illustrates two of the most dramatic evolutionary trends of VSAT systems (i.e., increasing throughput performance and decreasing cost).

When VSATs first started shipping in the mid-1980s the cost of a terminal was over $10,000, with data throughput of 9.6 to 64 kbps. Today the cost of a Ku- or Ka-band VSAT is in the hundreds of dollars, with throughputs of 10–20 Mbps. But the fundamental architecture of the VSAT system has not changed significantly. Most VSAT systems employ a star topology where a hub station transmits a forward channel to the remote stations, and the remote stations access an FDMA/TDMA return channel for the return channel. While this architecture was designed for the traditional 36 MHz C-band/Ku-band satellite design, it can also work well with high-throughput satellites employing spot beam architecture.
But high-throughput systems differ from traditional satellites in several key areas, including:
- High capacity beams of 100 MHz or more
- Gateway stations supporting as many as 10–20 spot beams and more than 5 Gbps of capacity
- High individual throughputs per remote station
- Sophisticated techniques to overcome rain attenuation, especially as required in Ka-band systems

Thus, the system requirements for VSATs have evolved quite significantly with the emergence of high-throughput satellites. As a case in point, Hughes has developed an extensive set of new technologies dubbed “JUPITER High-Throughput Technology”, which enable high bandwidth efficiencies on the space segment and Gateway stations as well as high-performance, cost-effective terminals for the end user. These technologies are discussed below, as well as how they can be applied to various service models.

**DVB-S2 Extensions**

Due to its excellent performance the DVB-S2 standard with adaptive coding and modulation (ACM) has been widely adapted in virtually every major VSAT system on the market. However, the DVB-S2 standard was conceived for traditional satellites employing coverage-optimized 36 MHz or 54 MHz transponders, typically yielding maximum symbol rates of 45 Msps with 16 APSK modulation. The new class of HTS satellites, with greater amount of spectrum per beam and with higher link capabilities, can achieve higher capacity by employing enhancements or extensions to the DVB-S2 standard. Hughes JUPITER technology applies a number of extensions to the DVB-S2 standard including support for higher symbol rates as well as support for higher modulation schemes.

**Highly-Efficient Gateway Stations**

Another striking evolution of VSAT requirements is the capacity required at the hub or Gateway station. This is closely related to the amount of channel capacity noted above, but manifests itself in hardware. A classic 36 MHz transponder, when supporting VSAT applications, will require a hub station that supports 80 to 100 Mbps of capacity. Most VSAT systems deploy this in a one or one-half rack solution. But a high-throughput satellite system with high bandwidth spot beam channels and multiple spot beams will result in Gateway stations that support from 1 to 10 Gbps of capacity.

Consider the implementation for a 5 Gbps Gateway. Using conventional VSAT practice where one-half rack typically supports 100 Mbps throughput, as many as 25 racks of equipment would be required, plus additional devices for packet shaping, routers, switches, and other equipment required to support the traffic requirements. Using this approach, the Gateway stations are quite large, consume a lot of power, and require significant environmental conditioning, all of which mean significant cost. Hughes JUPITER technology is able to achieve a Gateway “density” of over 1 Gbps per rack, and hence a compact 5-rack configuration for a 5 Gbps Gateway, achieving significant efficiencies relating to footprint, power consumption, and environmental conditioning. In addition, Hughes has designed the Gateway stations to be entirely autonomous and remotely operated. The autonomous design enables the various Gateway stations to interconnect directly into the Internet, thereby lowering operational costs, as there is no need to bring all the traffic back to a central data processing station. The result is a highly efficient “lights-out operation”, and with much lower cost, since there is no need for local staffing of Gateway stations.

**Higher-Performance Remote Terminals**

According to a recent study by the NPD Group, the number of connected devices per US household has grown to 5.7. As the usage of computer tablets and other personal devices continues to expand, this number should grow and it is likely that this phenomena will be seen in other countries. More devices, along with the increased consumption of video, means that the remote terminal needs to support ever increasing throughputs. Hughes is using JUPITER technology to bring to market a family of remote terminals that have significant throughput and processing capabilities. These JUPITER system terminals

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have the capability to support many Mbps of IP throughput. With a focus on even more bandwidth-demanding enterprise and government applications, Hughes—in the future—will be introducing specialized terminals with the capability to support up to 100 Mbps of IP throughput.

**Web Acceleration**

Physics dictates that communications over geosynchronous satellites will incur a delay of about 250 ms each way. The effect of this delay is compounded when data protocols rely on “hand shakes” or acknowledgements in order to continue transmitting data, which results in slow data throughputs. In the case of the typical Web user the result is a very slow screen “paint”, as Web objects are fetched one by one and the time to complete the display of an entire Web page can take a long time. To overcome this, many of the VSAT ground systems have implemented HTTP object pre-fetch. The Hughes implementation, TurboPage, works by reducing the chattiness involved in fetching objects that are part of a Web page. The TurboPage client intercepts Web requests on the remote router and talks to a TurboPage server at the data center. The normal process would involve waiting for a remote PC to parse the initial HTML page, sending a DNS (domain name server) request for each server that has an object such as an image or flash file, and then initiating multiple requests to each of those other servers to retrieve each required object. Instead, the TurboPage server prefetches the objects and caches them temporarily at the terminal, providing a local delivery of the requested objects rather than requiring an end-to-end request and response. TurboPage therefore assures the freshest content from the Web server, while delivering lightning-fast performance. Figure 13 illustrates the data flow of the TurboPage feature.

**Compression Efficiencies**

Beyond Layer 1 and Layer 2 enhancements, advanced VSAT designs can achieve significant capacity gains through a series of techniques including Performance Enhancing Proxy (PEP) as well as payload compression. The Hughes PEP implementation uses standard (RFC 3135) mechanisms for TCP ACK reduction and three-way handshaking, but has expansions beyond the standard to maximize “filling of the pipe” without congestion. The system also supports industry standard (RFC 3095) header compression tuned to the satellite link for IP, TCP, UDP, and RTP protocol suites. In addition, Hughes implements a powerful two-stage compression scheme for HTTP traffic. As illustrated in Figure 14, the first stage is a Byte Level Caching (BLC) algorithm which is a lossless compression scheme that exploits duplication of byte sequences in a data stream. A large cache is used by the BLC compression scheme to detect redundancy in data streams transmitted several megabytes in the past. BLC, therefore, can provide compression gains on both compressible (text/html) and non-compressible (images) data alike. The second stage is implemented using a V.44 compression scheme. The dynamic use of single-stage compression with BLC only, or two-stage compression with BLC+V.44 on a block-by-block basis, improves Web page response by selecting the compression scheme that optimizes compression gain and decompression time.
Challenges of Ka-Band

It is well understood that Ka-band, with higher frequencies than Ku-band, is subject to higher rain fades and that many consider this to be the most significant challenge to Ka-band networking. It is worth reflecting on the fact that when Ku-band was first popularized, many were similarly concerned about the impact of rain fade on Ku-band. Hughes JUPITER technologies have been developed with the highest levels of SLAs and QoS in mind and therefore have a rich set of features to mitigate attenuation due to atmospheric moisture. These features include the following:

- Forward channel mitigation techniques include:
  - Uplink power control at the Gateway stations
  - Satellite automatic level control
  - Gateway RFT diversity
  - Adaptive coding and modulation of the forward channel
  - Use of larger antenna to generate higher EIRP

- Return channel mitigation techniques include:
  - Uplink power control at the remote stations
  - Adaptive coding of the return channel
  - Dynamic symbol shifting of the return channel
  - Use of larger antenna to generate higher EIRP

The technology behind these rain fade mitigation techniques is the subject of a more detailed technology paper from Hughes but it should be noted that Ka-band has already been widely and successfully deployed in high rain areas. The experience of Hughes has been that Ka-band availability in the range of 99.7% can be achieved, even in high rain fade areas, such as Florida.

What To Do With All This Capacity

As we have seen, high-throughput satellites are able to bring large amounts of capacity to be used for data communications. But who will consume this capacity? What are the applications which will benefit from this capacity and thereby drive the satellite industry?

Internet Access

Any discussion of HTS applications should start with Internet access as this is the fastest growing application in the satellite industry today. With Internet access the key objective of service providers is to deliver a range of service plans and choices for different market segments. Importantly, the ground systems need to manage capacity effectively in times of high contention so that all users within each class of service gets equal and fair access. In addition, the ground systems need tools, in the form of bandwidth allowances, which ensures that individual subscribers do not monopolize the satellite capacity. Given the attractive economics of high-throughput satellites, service providers are able to offer monthly service
“quotas” that are competitive with 4G/LTE services. Figure 15 shows the capacity allocations advertised by Hughes for its HughesNet® Gen4 service in the U.S. By comparison, ATT advertises a more restrictive set of bandwidth allowances at higher prices. For instance, as of June 2013 ATT offers a 10 GB monthly plan at a price of $120 per month (not including additional devices). In contrast, the HughesNet Gen4 Power service for the same amount of bandwidth allowance is $40 per month.

**Figure 15. HughesNet Gen4 Service Plans**

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<thead>
<tr>
<th>EchoStar XVII</th>
<th>Power</th>
<th>Power PRO</th>
<th>Power MAX</th>
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<td>Bonus Bytes (GB)</td>
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**Internet for schools**

Numerous countries around the world are investing into infrastructure to bring high-speed Internet to schools everywhere, even in the smallest communities and villages. Satellite is an ideal solution in areas unserved or underserved by terrestrial technologies, such as DSL or cable. At a typical school, a large number of devices will be connected and active at any one time, thus driving the consumption of large amounts of capacity. High-throughput satellites can deliver exceptional economics for Internet access to serve education needs throughout the world. Figure 16 illustrates a typical education project from the Ministry of Telecommunications in Peru where many PCs are connected over a classroom WiFi cloud to a single satellite terminal.

**Figure 16. Schools Project In Peru**

**Cellular Backhaul**

As outlined in Figure 17, 3G and 4G cellular technologies enable high channel rates which, in turn, require higher bandwidth backhaul channels to support the traffic. While 3G and new 4G/LTE technologies are being rolled out for higher speed mobile data services, most of these services are being implemented in urban areas and major traffic arteries where terrestrial backhaul is available or justifiable, usually fiber or microwave. Providing coverage in ex-urban and rural areas is an emerging opportunity for satellite backhaul, as it can often be justified when distances to cellular base stations make it cost-prohibitive using terrestrial means. 4G services will be limited to urban centers, where fiber is readily available, for the foreseeable future. But mobile operators will continue to extend 3G services to ever more remote areas, thus creating an opportunity for high-throughput satellite systems to support the backhaul of 3G data services.
Enterprise High-Availability Networking

One of the strongest value drivers for satellite networks in enterprises is backup of terrestrial services, as illustrated in Figure 18. Combining terrestrial and satellite connectivity means there are two alternate network paths, ensuring the highest availability even when disaster strikes. In addition, the satellite path can be used to instantaneously deliver bandwidth where and when it is needed, which is especially important when backing up relatively low bandwidth DSL access lines.

On-the-Move Services

Continued growing demand for Internet connectivity everywhere is fueling high growth in mobility services, whether airborne, land or maritime. Wide beam, CONUS-type Ku-band satellite coverage is ideal for these kinds of services, and in particular, for applications over oceans and continent-wide areas. HTS Systems, as we have previously seen, can deliver large amounts of capacity economically, but the difference with HTS systems is that a mobile terminal will move across multiple beams thereby requiring multiple “hand-offs” from beam to beam. Hughes has developed a number of technologies, including Doppler compensation and fast outroute acquisition, which enable “on the move” over satellite whether for use on CONUS-type coverage or small spot beam coverage. With these technologies, operators can effectively deliver mobility services over both CONUS-type and HTS systems. But, it should be noted that not all of these systems can provide contiguous geographical coverage over a wide service area, and therefore, potential service gaps may occur.

Quality of Service

As with most terrestrial consumer Internet services, satellite Internet access for consumers is provided on a “best efforts” basis, which means that there are no contractual QoS (Quality of Service) or SLAs (Service Level Agreements). Conversely there is a need to employ FAP (Fair Access Policy) in order to prevent excessive bandwidth usage by the few from degrading service quality to the majority, which needs to be designed into both the customer modem and NOC (Network Operations Center) system. But to effectively support enterprise grade services, ground systems need a range of features and functionality that will satisfy the service quality and performance demanded by enterprises. Some of the essential features include the following:

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<tr>
<th></th>
<th>WCDMA (UMTS)</th>
<th>HSPA HSDPA/ HSUPA</th>
<th>HSPA+</th>
<th>LTE</th>
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<tr>
<td>Max downlink speed loss</td>
<td>384 kbps</td>
<td>1.4 Mbps</td>
<td>28 Mbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Max uplink speed loss</td>
<td>128 kbps</td>
<td>5.7 Mbps</td>
<td>11 Mbps</td>
<td>50 Mbps</td>
</tr>
</tbody>
</table>

Figure 17. Data Rates for 3G/4G Services
Guaranteed bandwidth throughput
Tight latency and jitter specifications
Very high network availability
Support of private IP addressing
VLAN Tagging
Prioritization of traffic based on any combination of values in the headers
Support for various routing protocols, including BGP
Encryption and conditional access

**HTS Technology Flowthrough**

As much as the industry talks about high-throughput satellite systems, whether over Ku-band or Ka-band, traditional satellite capacity will continue to be important for VSAT networking. There are many areas in the world that will not see high-throughput satellite systems deployed for a long time. Further, certain market sectors and applications lend themselves better to using conventional satellite capacity. An exciting prospect is that these markets will be able to leverage the ground system technologies developed for high-throughput systems. These benefits will likely include:

- Smaller footprint hub stations – as Gateway stations achieve higher density, these same designs will lend themselves to very small footprint for 100–200 Mbps of capacity. This smaller footprint makes these hub systems more scalable and opens more possibilities of supporting multiple transponders/satellites from a single hub station.

- High-performance remote terminals – the same remote stations which provide multi-Mbps throughput over a high-throughput system can also be used over conventional satellite capacity. This will enable operators to put into service cost-effective remote terminals supporting up to 50 Mbps of TCP throughput.

**Conclusion**

High-throughput satellite systems represent the next generation of VSAT networking, enabling better economics and higher performance broadband service levels globally. The impact on the VSAT industry can be seen in Figure 19, which shows the number of VSAT sites in service and active over the past 25 years. Notably, the launch of high-throughput satellites starting in 2005 (with the launch of Thaicom IPStar) has served to dramatically accelerate the growth of the VSAT service business.
In conclusion, high-throughput satellites are opening up exciting new vistas for cost-effective broadband connectivity and applications globally, driven by demand for high-speed Internet access by populations either unserved or underserved by terrestrial broadband. This trend is expected to fuel continued healthy growth of the VSAT industry as a key part of the world’s mainstream telecom infrastructure. As the inventor of VSATs and worldwide leader in broadband satellite networks and services for home and office, Hughes will continue to make major investments to advance the technologies and value-added performance of related products and services—no matter the band and for all market sectors globally.

Proprietary Statement

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