HOW AND WHY COMMERCIAL HIGH-CAPACITY SATELLITES OFFER SUPERIOR PERFORMANCE AND SURVIVABILITY IN THE FUTURE SPACE THREAT CONTINUUM

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ABSTRACT

The Department of Defense (DoD) Deputy Assistant Secretary of Defense for Space Policy, Douglas Loverro, referring to new commercial High Capacity Satellite (HCS) communication services during the testimony to the HASC Space Posture Hearing in March 2016, stated that "technologies and opportunities of greatest significance for national security space today are being paced by advances in the commercial space sector."

Today's leading commercial HCS broadband service providers – driven by bandwidth economics and consumers' exponentially increasing appetite for capacity – are supplying services, inclusive of improved commercial end-user or warfighter terminals, that are delivering order(s) of magnitude improvements in on-orbit capacity and capacity economics. These attributes enable these new satellite broadband businesses to enter markets that previous wide-beam or "old space" L-, C-, X-, Ku-, Mil-Ka-, and Mil-Q-band satellites couldn't economically serve. The Department's purpose-built Advanced Extremely High Frequency (AEHF) and Wideband Global Satcom (WGS) satellites, along with use of leased commercial Ku-band satellites, typically provide 1.5 to 4 Gbps of capacity or busy-hour deliverable bits. Meanwhile, these "new space" commercial HCS providers are using on-orbit communication satellites with over 140 Gbps of capacity, greater than 35-fold improvement, and promise single communication satellites with over 1000 Gbps by the year 2019, a greater than 250-fold improvement over current old space systems.

The technologies that commercial HCS broadband service providers use to achieve order(s) of magnitude improvements in capacity and economics are essentially the same technologies that enable dramatically improved mission performance and survivability. The net result is that these leading commercial HCS broadband service providers are supplying services that offer the Department both superior performance – in terms of communication speed or throughput, availability, and equipment size, weight, and power – and survivability against the future space threat continuum.

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The leading commercial HCS service providers are supplying services, inclusive of improved warfighter terminals, that deliver order-of-magnitude improvements in end-user performance from a speed and equipment perspective, increased availability, superior anti-jam and cyber protection over DoD purpose–built communication satellites, and order-of-magnitude improvements in cost of delivered capacity.

The satellites used for DoD Wideband Satcom, namely AEHF, WGS, and leased commercial Ku-band, were constructed with attributes enabling "broadcast" efficiencies to cover large land areas. These general purpose Fixed Satellite Services (FSS) or broadcast attributes optimize delivering the same bit or channel, i.e., a live event or Global Broadcast System (GBS) video feed, across a broad geographic area. In some cases protective or survivability features have been added to enable minimizing the effect of interferers, especially on AEHF and X-band WGS.

Broadcast and large coverage are no longer the leading driver of bandwidth economics. With the introduction of PCs, tablets, and smart phones, the new driver is that each user wants individual, interactive content. This shift first occurred terrestrially, and is now happening in commercial HCS broadband services.

DoD purpose-built AEHF and WGS together with leased commercial Ku-band communication satellites, typically provide 1.5 to 4 Gbps of capacity or busy-hour deliverable bits. Meanwhile, "new space" commercial HCS providers are using on-orbit communication satellites with over 140 Gbps of capacity, a greater than 35-fold improvement, and promise single communication satellites with over 1000 Gbps by the year 2019, a greater than 250-fold improvement over current old space systems.

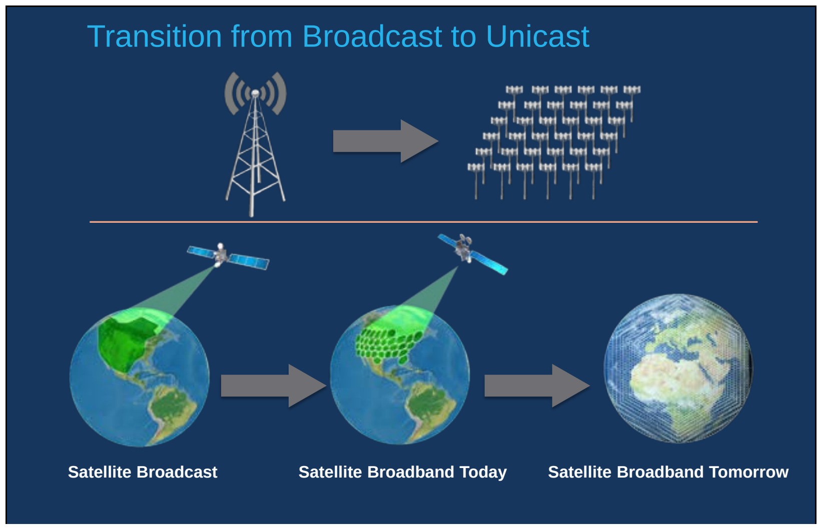

Exhibit 1: Broadcast to Unicast - leading commercial HCS service providers are paralleling the shift in terrestrial communication, employing smaller and smaller beams to maximize frequency reuse.

Many of the enabling technologies and techniques used to dramatically increase the capacity and thus increase end-user speeds, reduce end-user terminal size and cost, and reduce the cost of delivered capacity, also address many elements in the future space threat continuum from a resilience and availability perspective. These technologies and techniques parallel the shift that occurred in terrestrial networks in the transition to digital cellular. It was the transition from broadcast to unicast and the development of small cells to increase frequency reuse that allowed more users, with more capacity, for the same (or lower) cost in the same geographic area.

This shift to unicast, interactive broadband-optimized satellite network architectures also provides inherent availability, anti-jam capability, resilience and security to commercial HCS satellites. One key element is increasing the number of satellite spot beams, from tens, to hundreds, to thousands as the technology is developing over the course of this decade. As the number of spot beams increases, the anti-interference performance of each spot beam must also increase. When communication systems, whether they are terrestrial or space-based, support larger and larger numbers of users, with more aggressive frequency reuse, the systems must be engineered to share the available resources (spectrum) more efficiently. Individual users must share the resources (in time, frequency, and geography) among a large number of other users. When many users are sharing the available resources, the system must have mechanisms for separating and resolving the signals associated with all users.

From a single user perspective, each user operates in a sea of thousands (or millions) of interference sources—namely the other users. The technologies that allow cutting-edge HCS networks to mitigate the interference from thousands of other spot beams and millions of other users are the same that allow these systems to operate through the continuum of current and future space threats.

Broadcast networks, with large coverage areas serviced by small numbers of beams that span large geographic areas, also tend to me more susceptible to wide-ranging or total disruption by a small number of interference sources. Conversely, modern HCS systems with large numbers of spot beams and interference mitigation technologies as a foundational design concept, are much more capable of limiting (or completely eliminating) the effect of large numbers of interference sources.

END-USER PERFORMANCE

To answer the shift in the market to satellite broadband, HCS are now being optimized to meet the requirements of focused, unicast, interactive broadband, as opposed to wide area broadcast. Today's new end-to-end commercial HCS communication systems can dramatically improve mission performance, provide greater resilience, and improve affordability. Commercial HCS, like ViaSat-1, are specifically designed to optimize the economics of two-way broadband communication, which means maximizing the amount of user speed and capacity, or the pool of bits, that are generated for a given total end-to-end investment including satellite, launch, insurance, ground segment, and operations.

As a result of the shift to unicast-maximizing architecture, performance, and cost for individual users has improved significantly. Exhibit 2 shows the contrast between the performance of WGS and the Department's leased Ku-band networks serving Department's airborne, ground, and maritime missions on top and the corresponding performance of assured high-speed commercial HCS services on the bottom.

The lack of bandwidth at an affordable cost inherent in legacy DoD networks has forced users to deal with congestion and balance end-user performance, availability and priority with the available capacity and capacity cost, rather than simply being able to use what they need to perform any given mission. Many users are left without access to AEHF and WGS systems because higher-priority users are consuming the limited, highly congested resources.

Since 2012, new commercial HCS satellite broadband services have shown that they can effectively complement mainstream terrestrial broadband – validated by the FCC Measuring Broadband America benchmark report. Three years in a row the FCC has found that the ViaSat HCS network architecture (used by both ViaSat and HughesNet) is superior in delivering promised speeds (12-15 Mbps to the home and 3 Mbps return) when compared to all other U.S. consumer broadband offerings included in the report, including cable, DSL, and FTTH.

A fundamental aspect of providing this kind of broadband service that exceeds expectations is having both sufficient capacity to prevent network congestion or oversubscription in busy hours, and also a cost of capacity enabling affordability with respect to market alternatives. Commercial HCS satellite broadband services are committed to providing satellite broadband that achieves terrestrial broadband performance for decades to come.

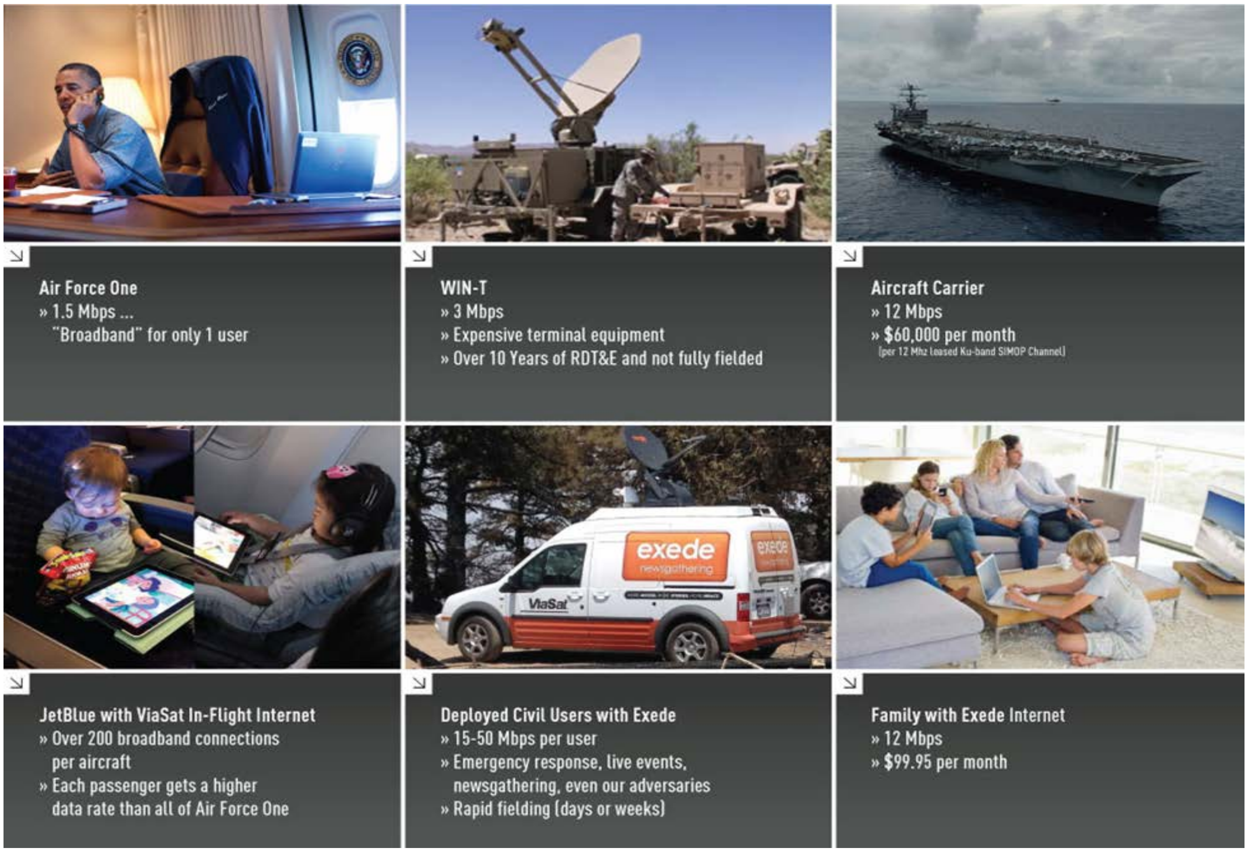

Exhibit 2: End-User Performance - leading commercial HCS service providers are serving the commercial broadband and live events markets with higher speed data delivery, smaller and lighter terminals, and lower costs to provide superior performance.

To provide the expected level of commercial service requires providing ample bandwidth to support the services that commercial users demand (such as streaming video like SKYPE and Netflix, secure web browsing, and gaming) as well as managing congestion and oversubscription continuously. It would be presumptuous to say congestion will never occur (note that wireless carriers recently had to spend over $100 million to temporarily boost capacity to head off congestion at Super Bowl 50). However, a new $500 million investment in second generation commercial HCS represents our commitment to continuing to build on our network performance, achieving new levels of broadband user experience.

In November 2015, ViaSat introduced a preview of this next generation system by offering 25 x 3 Mbps service plans to commercial subscribers, the fastest residential broadband ever in the U.S. and the first to meet the new 25-Mbps FCC definition of broadband speeds, together with virtually unlimited data. Customer satisfaction with network performance jumped, with churn (customers dropping the service) among the new service plan subscribers dropping to historic lows. For the Department, this FCC definition of performance and availability should establish a new requirement mark for our warfighters.

HCS systems, along with terrestrial communications systems must adapt to an increasing appetite for bandwidth from consumers, while keeping retail costs relatively constant. In the last decade, users have expected an order of magnitude increase in available bit-rate, while paying roughly the same price per month for service. To service this demand, HCS systems must provide more and more capacity for roughly the same cost. Bandwidth economics of this scale are driving HCS providers to innovate at an exponential pace, and many of these innovations that enable the resilience, anti-jam, and availability of commercial HCS networks could be leveraged by the U.S Government for its military satcom needs.

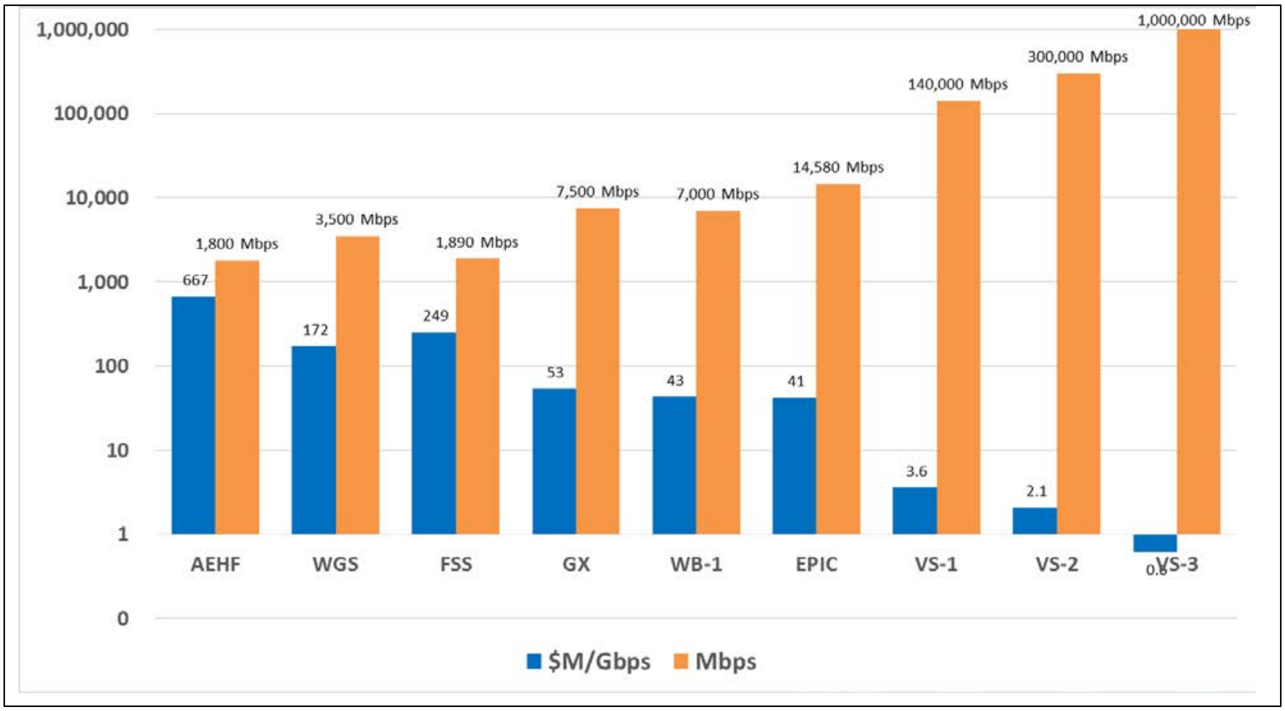

Exhibit 3: Over the last decade, overall capacity per satellite has increased by three orders of magnitude, while cost per unit capacity has similarly decreased by three orders of magnitude. This innovation has been driven end user's increasing appetite for capacity.

PROTECTION/SURVIVABILITY

As shown in Exhibit 4 the next big step for these commercial HCS services will use HCS that provide visible earth coverage, with a very large number of very small spot beams, creating an enormous amount of capacity. Near future (2019) HCS systems will provide over 1000 individual Ka-band spot beams and over 1000 Gbps of capacity ***per satellite***. Each of these satellites will have more capacity than the full complement of capacity supplied by the 400 commercial communications satellites in space today. These services will be sized to deliver enough capacity to enable more consumer choice with an affordable, high-speed, high-quality internet and video streaming service. The same technologies and techniques used to create this capacity also provide inherent availability, anti-jam capability, resilience, and resistance to collection/exploitation to commercial HCS satellites. The key is the increased number of satellite spot beams, from tens, to hundreds, to thousands as the technology undergoes a transformation in this decade similar to that of terrestrial communications over the previous two decades.

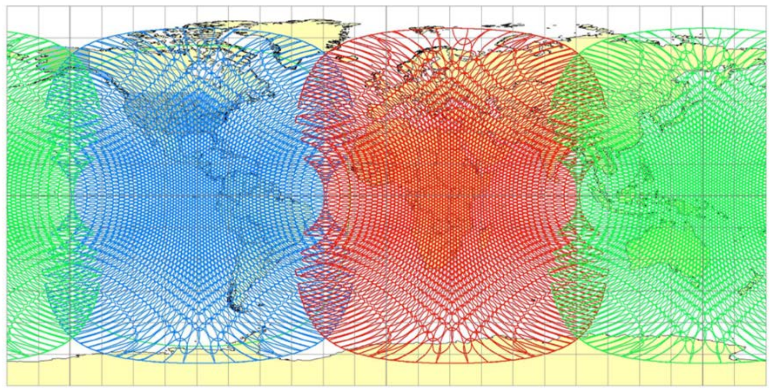

Exhibit 4: Global Broadband Coverage – ViaSat-3 platform delivering more than 1,000 Gbps - or 1-Terabit per second (Tbps) - of network capacity per satellite to enable high-speed internet, including video streaming.

Resistance to Interference

The leaders in commercial HCS services are in fact purposely building their satellite services to be invulnerable to the continuum of known and anticipated threats including unintentional and intentional jamming, cyber intrusion, unauthorized collection, physical attack, weather, etc. These systems are being market-driven to provide very high levels of availability in the presence of these real-world threats because of the high reliability that our customers demand from our services.

Geographic Gain Isolation

Market economics have driven commercial HCS providers to maximize capacity by aggressively re-using frequency with many small spot beams arranged into a honeycomb-like grid of beams. When creating a service pattern of densely packed grid of beams and aggressive frequency reuse, HCS networks typically partition the available spectrum into smaller “channels,” with the creation of a grid where each beam uses only one of the channels, thus allowing beams to be geographically adjacent without interfering. For example, consider a scenario where an HCS system has 1 GHz of spectrum, with two polarities available. The spectrum could be divided into two frequency bands of 500 MHz each, with the two non-interfering polarities allowing for a total of four channels. To ease communication and visualization of this channelization concept, HCS designers typically assign a color to a given channel and refer to these systems as multi-color frequency reuse patterns.

When creating multi-color reuse patterns, HCS designers attempt to organize the beams so that same colored beams are separated from each other. Even though a given color beam doesn't have an adjacent same-colored beam, there are several nearby beams that provide a source of interference. Generally, a three-color reuse pattern is the most aggressive pattern that can provide complete coverage of a geographic area, while patterns of 4, 6, and 8 colors are also common. Using more colors diminishes the interference from nearby beams, using fewer colors maximizes capacity via frequency reuse. HCS designers must trade interference performance against frequency reuse to maximize the capacity of their systems. Exhibit 5 notionally illustrates several multi-color frequency reuse patterns.

Channel Color	Frequency Band	Polarity
Red	Lower 500 MHz	LHCP
Yellow	Upper 500 MHz	LHCP
Black	Lower 500 MHz	RHCP
White	Upper 500 MHz	RHCP

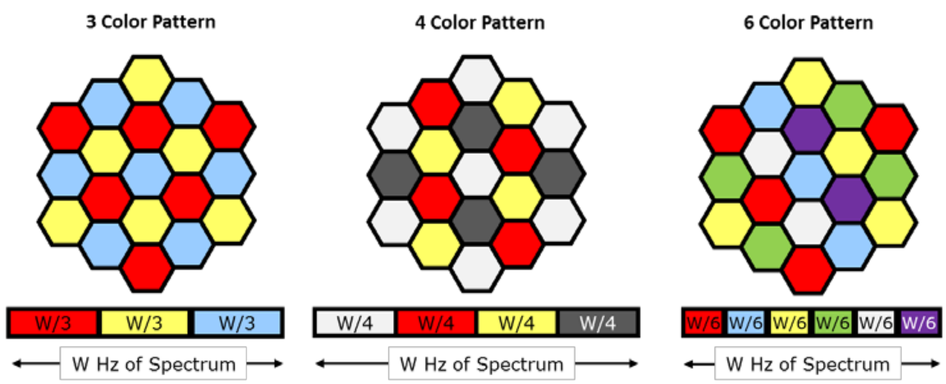

Exhibit 5: Grid-of-Beams – A 3 color grid of beams patterns maximize frequency reuse and interference from nearby beams, while adding more colors reduces effective frequency reuse and reduces interference. The sweet-spot of maximized system capacity depends on the ability to mitigate interference.

Exhibit 6 shows a notional 4 color reuse pattern over a large land mass. Note that each beam color has multiple nearby beams with the same color—each with thousands of users, which taken together are roughly equivalent to a high powered interferer.

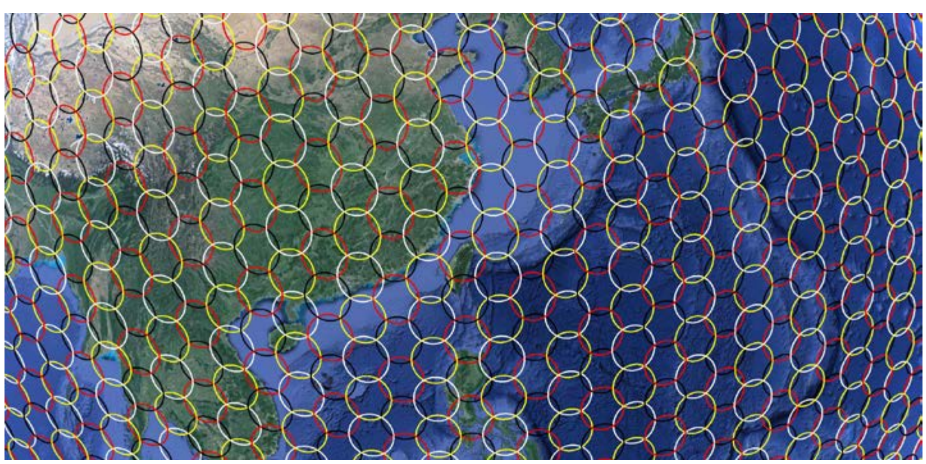

Exhibit 6: Grid-of-Beams – A notional 4-color reuse pattern over a large geographic area. Note that even though same colored beams are never adjacent to one another, there are many same-colored beams (interferers) nearby.

To manage the interference from nearby beams, HCS satellites must have very steep gain roll-off contours for their beams. Exhibit 7 shows the actual beam roll-off contours for the south Florida beam of ViaSat-1. It highlights the -30dB contour which reduces the effect of a transmitter by a factor of a 1000 compared to a terminal in the beam center. The net result is with 2011-era ViaSat-1 technology, an interferer in Cuba would have little to no effect on south Florida.

Exhibit 7 also shows the more advanced beam coverage of ViaSat-3. This satellite, scheduled to be on orbit in 2019, will feature even smaller beams with better roll-off contours. In this specific case, a powerful interferer in Key West would not impact Miami. The key point is that the advancing grid of beams technology, necessary for increasing frequency reuse by mitigating interference from nearby beams and increasing overall capacity, also has the capability to mitigate and defeat high-power interferers, both intentional and unintentional.

Contrast this to leased Ku-band beam (Exhibit 8) coverage over Europe that would typically provide a -4 to 6 dB drop from the center of the continent to a distance well off in the Atlantic or North Africa or the Middle East and Russia. An adversary with a jammer in the Middle East could completely disrupt European coverage in this scenario.

It's not that the Department's AEHF, WGS, and leased Ku-band network satellites didn't have the same market-driven demand that make them more vulnerable to these threats, instead it is the fact that these prior generations of satellite architecture, both Department purpose-built and leased commercial Ku-band, are based on attributes enabling "broadcast" efficiencies, to cover large land areas.

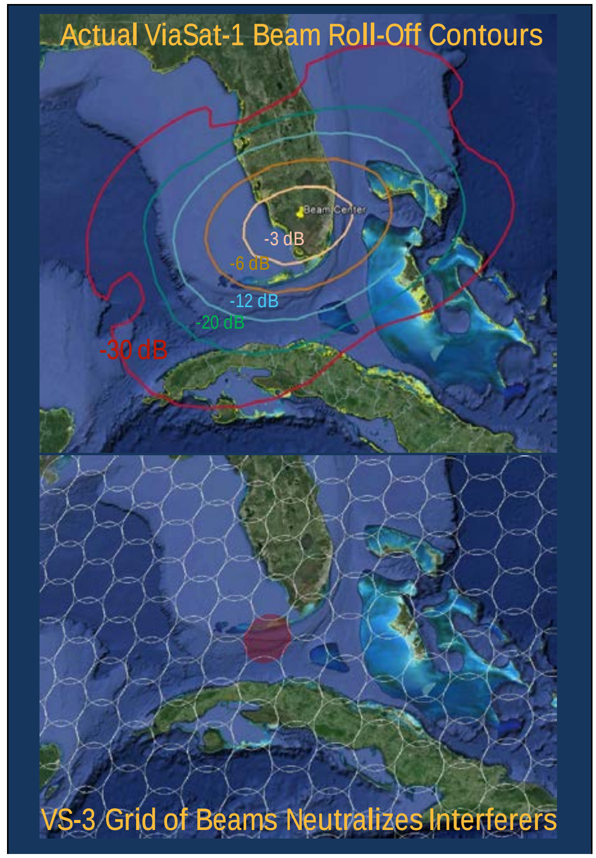

Exhibit 7: Grid-of-Beams – high network availability, resiliency, and anti-jam are inherent capabilities of HCS broadband networks.

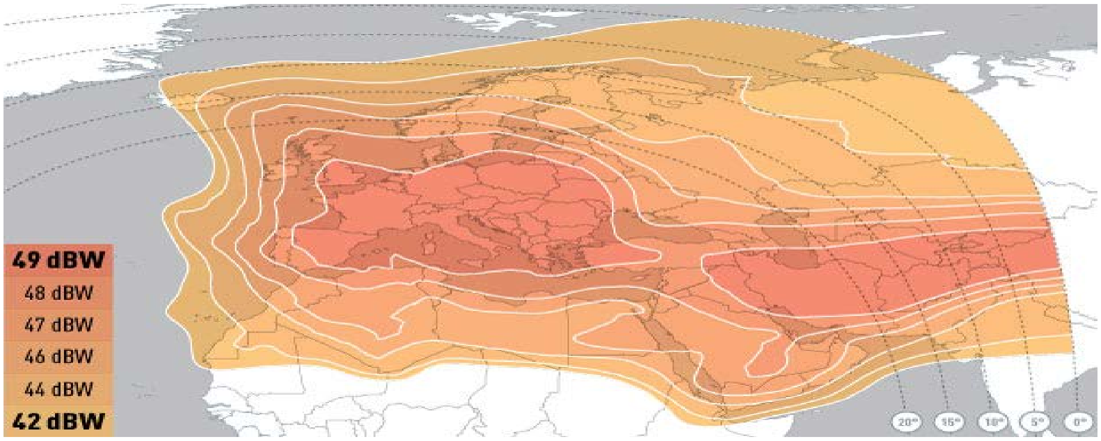

Exhibit 8: Ku-Band roll-off parameters on a broadcast optimized communications satellite.

Simply based on beam gain contour performance alone, modern HCS communication networks significantly outperform WGS and AEHF in an environment where high-powered (>90 dBW) interferers are present. Based on gain-contour interference rejection, the effect of interference sources are limited to the beam in which the jammer is present. In the case of AEHF and WGS, where beam sizes are large (1.5°-2.0° and larger), the affected area encompasses many thousands of square miles, and in the case of a Pacific satellite, a significant area of the western Pacific Ocean. Additional beams may also be degraded due to the more gradual roll-off contours on these satellites.

In the case of an HCS, an interfering source will degrade only the beam in which it is resident, and since the beams are very small with very steep roll-off contours, the interfering source will have an effect only within a very small geographic region (a few hundred square miles or less). In a western Pacific scenario against a land-based interference source, high data rate communications very close (<100 km) to the coastline are possible. And this analysis only considers gain contours associated with the beam – modern HCS systems have additional capabilities that further mitigate interference. Several independent evaluations have been performed by the U.S. Government which confirms these results.

Frequency Use and Spectrum Availability

Another aspect of resistance to uplink interference is the amount of instantaneous bandwidth available for use in the communication system. The larger the bandwidth occupied by a communication system, the larger the bandwidth that an interferer must occupy to disrupt that communication system.

System Type	Available Bandwidth
Leased Ku	37 MHz Transponder
WGS	125 MHz Channels (switchable/configurable)
AEHF	2 GHz
HCS—ViaSat-1 (2011)	1.5 GHz (two polarities)
HCS—ViaSat-2 (2016)	2+ GHz (two polarities) (switchable/configurable)
HCS—ViaSat-3 (2019)	3+ GHz (two polarities) (switchable/configurable)

Clearly, leased Ku-band services are the most vulnerable, as each transponder occupies a relatively narrow band. WGS uses a relatively small bandwidth, but does have configurable channelization parameters that allow some level of resilience. AEHF provides a large transponder bandwidth (especially for its time), but commercial HCS systems will soon provide even larger instantaneous bandwidths that are flexible and configurable into various channel configurations.

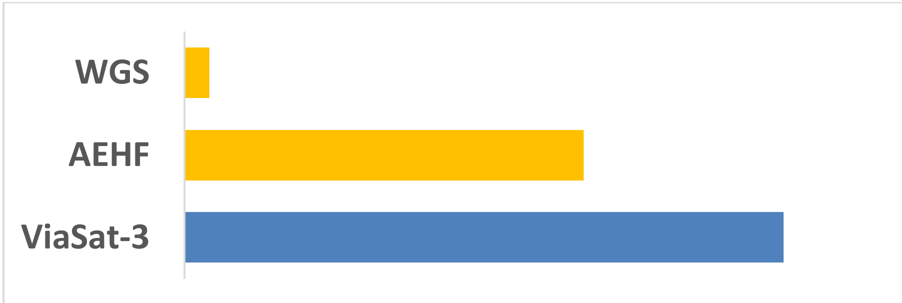

Exhibit 9: Available Spectrum: Capacity demands and technology improvements are driving commercial HCS to use larger and larger bandwidths.

Beam Frequency and Polarity Agility

Current HCS satellites, such as ViaSat-1 and Echostar XVII (Hughes Jupiter) have fixed beam configurations. Each beam is assigned a certain frequency and polarity configuration. This configuration is not easily changed and remains relatively static over the life span of the satellite. Next generation HCS systems, such as ViaSat-3, Eutelsat Quantum, and others will feature fully configurable beams. The frequency and polarity of a given beam (or the entire grid of beams) can easily be changed, on the fly, in near-real time. This agility can provide a significant advantage when dealing with interference. If a powerful interference source is detected in the current frequency, the system can simply move to another band and avoid the interference.

SUMMARY

This paper has demonstrated that commercial HCS providers—driven by bandwidth economics and consumers' exponentially increasing appetite for capacity—are supplying services that are delivering order(s) of magnitude improvements in on-orbit capacity. These attributes enable these new satellite broadband businesses to enter markets that previous wide-beam or "old space" satellites couldn't economically serve.

"New space" commercial HCS providers are using on-orbit communication satellites with over 140 Gbps of capacity, greater than 35-fold improvement, and promise single communication satellites with over 1000 Gbps by the year 2019, a greater than 250-fold improvement over current old space systems, all at orders of magnitude lower cost.

Department paid $5B for 37 Gbps			North America Customers paid $1.6B for 262 Gbps		
DoD Satcom / Operations	GFY 15 Capacity Gbps	GFY 15 Cost($Bs) $Ms / Gbps	CY 15 Revenue ($Bs) $Ms / Gbps	Calendar 2015 Capacity Gbps	Satellite Broadband
Gov't Purpose Built • 3, MUOS @ 0.12 Gbps • 3, AEHF, @ 5.4 Gbps • 7, WGS, @ 16.1 Gbps	22 Gbps	~ $0	$1.6B	262 Gbps	North American HCS • Jupiter-1, Spaceway-3 • Anik-F2, WB-1, ViaSat-1
Leased Ku-Band	15 Gbps	$1B	$0		
Operation Fees (Services pay O&M to DISA for Teleports, fiber backhaul, NOC, etc.) • Army $2.1B, 52% • Navy $.6B, 14% • USMC $0.1B, 3%, • Air Force $1.2B, 31%	n/a	$4B Understated by use of MILPER	$0 Included in Subscription		Operation Fee (NOC, SOC, Fiber, Backhaul, Call Center, Billing)
subtotals	37 Gbps	$5B	$1.6B	262 Gbps	
Understated by Satellite, Gateway, and Network/Waveform RDT&E & Procurement		$137 M/Gbps	$6 M/Gbps	Includes Satellite, Gateway, and Networking. No RDT&E and Procurement	

Exhibit 10: Delivered Cost – on a normalized basis of peak deliverable capacity, or bits, the Department would receive over a 20-fold more Speed & Capacity Value for their investment by using the industry leading commercial HCS service providers.

The economic motivation to maximize network capacity and availability has driven HCS providers to innovate at an exponential pace to create systems that employ a variety of features (capacity, interference mitigation, available spectrum, situational awareness, cyber security, gateway diversity, redundancy and resilience) that allow commercial HCS to provide assured communications that outpace military satcom systems in nearly every performance measure, all at a significantly lower cost per bit.

As shown in Exhibit 6, the geographic gain isolation of smaller spot beams cuts the effect of jamming attempts, even if interferer and target are in very close proximity. This attribute alone will allow HCS systems to outperform WGS and AEHF. Additionally, the available instantaneous bandwidth, frequency agility of next generation HCS systems like ViaSat-3 will outperform the similar features on DoD military satcom systems.

Additionally, commercial systems provide a high level of situational awareness. Network operators must be able to quickly determine events at the network level, such as weather events, beam outages, or gateway failures as well as events related to users, such as lowered performance related misaligned antennas, or foliage blocking user terminal line of sight. The ability to change the focus from events holistically at the network level down to individual performance (and data flows) for each user, and everywhere in between, is a hallmark of modern HCS network management systems. Situational awareness also forms the basis for a modern, active cyber defense—which is beyond the scope of this paper. When the network is capable of sensing data patters and flows (including ports, source, and destination addresses and traffic volumes) for individual users, advanced analytics can be employed to detect (and mitigate) cyberattacks in real time.

Taken together, these features will lead to orders of magnitude increases in performance, allowing DoD users to operate with assured communications in environments that were previously considered denied, all for a fraction of the cost per bit of current military satcom systems.

If it was possible for the DoD to lease high capacity commercial satellites today, for its entire broadband satcom consumption, they could in concept have 10 times the capacity (or the same capacity available on 10 redundant paths), for 1/10th the cost of the current annual leases, a savings of over $1 billion annually. Though it is not practical to do this today on a global or worldwide basis due to the regional deployment of these new satellites, transitioning to these satellite services where they exist would permit COCOM communications planners to program substantial usage margins for wartime contingencies, and aid transition to a global HCS system as it becomes available in 2019.

This transition would provide much needed additional (and/or redundant) capacity to the warfighter and represents a 100 fold economic benefit to current DoD practice where these satellites are available. With leased costs alone in excess of $1.2 billion annually, this could represent significant annual savings plus enhancing capability and resilience for mission assurance and success.

We hope this paper helps to form a market data baseline of commercial HCS and satellite services to inform the Department's upcoming Wideband Analysis-of-Alternatives (AoA) to determine if the performance cost benefit of commercial HCS and satellite services offsets platform/terminal modifications necessary to employ them.

