X-band Unmanned Aerial Vehicles (UAVs): Optimizing satellite communications to maximize UAV advantage

It is no secret that the use of Unmanned Aerial Vehicles (UAVs) is increasing. Market projections reflect growth in this global market of over 14.5 percent CAGR over the next decade, estimated to be $20.71 billion in 2018 and $52.3 billion by 2025. This growth is being fuelled by rapid advancements in smaller, lighter, and more efficient sensor payloads and equipment, airframes and engines, which together give UAVs greater endurance, longer range and greater autonomy. Greater autonomy naturally implies an ability to operate beyond-line-of-sight (BLOS) from the operator, which implies the use of satellite communications (SATCOM). While the typical consumer answer has traditionally been the use of the common Ku-band radio frequency (RF) spectrum, military and government consumers have X-band, a powerful SATCOM option available exclusively to them. X-band is purposefully reserved for government use only because it offers significant all-weather performance advantages, operational flexibility, and cost savings. Todd Dudley, Director, International Business Development at XTAR explains.

The all-weather performance of the X-band RF spectrum – and X-band UAVs – centers on X-band's extreme resistance to a form of atmospheric attenuation known as 'rain fade.' X-band SATCOM, at 7.25-8.4GHz on the RF spectrum, sits below the 10GHz threshold where the size of water droplets, ice particles, salt fog, and even airborne dust and sand, begin to cause reflection and refraction – i.e. attenuation – of an RF signal. This isn't magic, it is science: Lower frequencies attenuate less and thus travel further than higher frequencies through severe weather conditions, as depicted in Chart 1:

There are three common ways that Ku- and Ka-band UAVs can counter the effects of weather:

1. Additional Link Margin. The first and most common measure to address weather attenuation is to add additional link margin (bandwidth and power, if available) to maintain the SATCOM link. This quantity of additional bandwidth and power, known as space segment, can be enormous – and enormously expensive – as Figure 1, below, demonstrates: For operations in a Mediterranean climate, a Ku-band UAV requires 140 percent more space segment than an X-band UAV for the same level of service availability. A Ka-band UAV requires 510 percent more space segment than an X-band UAV. The additional space segment required for Ku- and Ka-band UAV operations in a tropical environment can be far higher. X-band UAVs naturally enjoy extremely high service level availabilities while using very little space segment.

2. Adaptive Coding and Modulation (ACM). Ku and Ka-band SATCOM users may also have to use ACM to help counter attenuation. This method applies different combinations of modulation and forward error correction (FEC) to a data stream to counter the effects of weather attenuation as a signal degrades in poor weather. ACM can significantly degrade throughput, however, and is particularly difficult to use with certain types of data streams because, when active, ACM can slow down voice communications and live video feeds, quickly rendering them unusable in bad weather. Because of X-band's all-weather characteristics, X-band UAVs do not need to employ ACM, and can transmit extremely stable voice, data, and even high-definition video links with extremely high service level availabilities.

3. Uplink Power Control (UPC). UPC is another way to stabilize a SATCOM link being impacted by weather attenuation. UPC increases transmit power from a UAV during poor weather,

Photo courtesy of US Navy

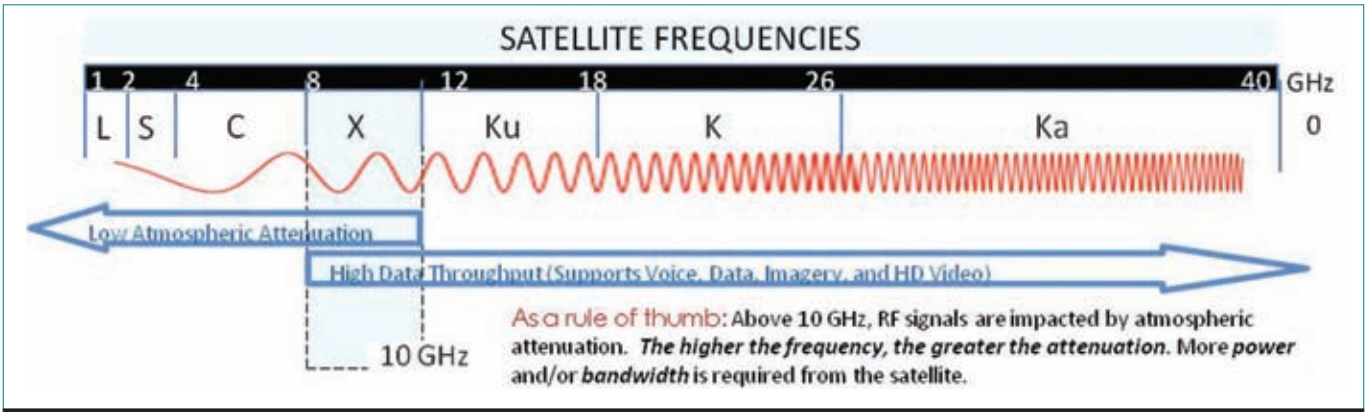

Chart 1

although this option is not generally an option on UAVs because they generally do not want to carry the extra size or weight of a higher-power amplifier for this occasional-use scenario.

The science behind X-band SATCOM performance

In the example below, a SATCOM link is closed between a UAV operating above Benghazi and a tactical operations center located in Tripoli without the use of ACM or UPC. As Figure 1 demonstrates, an X-band UAV would require less than 1dB of link margin to successfully operate in this region. A Ku-band UAV would require 2.6dB of link margin, which equates to 140 percent more space segment than an X-band UAV. A Ka-band UAV would require 8.1dB, which equates to 510 percent more space segment.

X-band UAVs perform naturally well in inclement weather without the use or additional cost of these technologies, making them far more effective - and lethal - than their weather-dependent counterparts.

Typical Rain Attenuation for 99.5 percent Availability (Tripoli to Benghazi)

Satellite Band	Link Margin (dB)	% Extra Space Segment (MHz) Required
X-band	< 1	-
Ku-band	2.6	140%
Ka-band	8.1	510%

Figure 1: Ku- and Ka-band UAVs can require significantly more space segment (and cost) than X-band UAVs

Photo courtesy of US Navy

X-band's extreme resistance to rain attenuation is matched by its extreme resistance to attenuation from sandstorms and airborne dust, both very real concerns in today's theatres of operation.

The table below provides some data taken from the paper 'Mathematical Model for the Prediction of Microwave Signal Attenuation Due to Dust Storms' to illustrate the effect of frequency on RF signal attenuation in dust.

Predicted Dust Storm Attenuation for Dust Particles of 50 µm

Satellite Band	*Frequency (GHz)*	*Attenuation (dB/km) for Visibility of 50m*	*Attenuation (dB/km) for Visibility of 10m*
X-band(up/downlink)	***8***	***0.1***	***0.5***
Ku-band (downlink)	*12*	*0.5*	*2.5*
Ku-band (uplink)	*14*	*0.6*	*3.0*

Figure 2: Signal attenuation due to suspended dust particles. Source: http://www.jpier.org/PIERM/pierm06/11.09021906.pdf

As shown in the table, signal attenuation at X-band is low even for storms creating visibilities of only 10m. As with rain attenuation, significant additional amounts of space segment (400-500 percent more) should be incorporated into the satellite links to overcome attenuation due to dust storms. If not addressed, these figures translate directly into link instability, which needlessly risks lives and mission failure.

If addressed, these figures translate directly into additional financial costs, which needlessly drain financial resources that could be spent on providing boots, bullets, and additional combat power.

Operational flexibility – and high throughput

While Ku and Ka-band satellites are rapidly trending towards smaller, more focused high throughput satellite (HTS) beams, there are distinct advantages to operating on X-band's large 4° and 4.5° spot beams. Namely, X-band UAVs can more easily support a much larger battlefield/surveillance area than Ku or Ka-band UAVs on HTS.

Narrow spot beams can significantly challenge a commander who needs the ability to dynamically re-task his in-flight UAV assets anywhere under his authority without having to worry about invisible HTS boundary seams, hand-off issues, and keeping his datalinks – and the soldiers, sailors, airmen, and Marines who depend on them – alive.

As Figure 3 demonstrates, wider spot beams offer X-band UAVs an impressive amount of operational flexibility to a military commander.

Figure 3: The use of X-band's larger spot beams, combined with bits/Hz efficiencies greater than Ku-band on HTS, allow X-band UAVs higher throughput and a greater operational flexibility than their Ku- and Ka-band counterparts.

The traditional 'trade-off' for using larger spot beams, of course, has been lower rates of data throughput. Not so with X-band. Both Ku and Ka-band have strict limits on EIRP/power density because Ku and Ka-band satellites are spaced as close as 2° apart, and sometimes closer (Figure 4). Because X-band satellites are spaced a minimum of 4° apart, X-band UAV terminals can operate at higher, more efficient spectral power densities and thus can often achieve higher throughput per megahertz (bits/Hz), than on Ku or Ka-band. While actual throughput depends on many factors, in one field test, X-band achieved bits/Hz efficiencies 2.5 times greater than Ku-band on HTS, measured on the same SATCOM terminal.

These two aspects of X-band UAVs – the use of broad spot beams, and an ability to operate at higher spectral power densities - make long-range, high-endurance battlefield support or maritime surveillance missions not only easy, but affordable as well.

Cost savings - and MILSATCOM compatibility

The cost savings associated with operating at higher, more efficient spectral power densities and with lower link margins can be staggering, when recognizing that a military commander has to purchase 140 percent more Ku-band space segment and 510 percent more Ka-band space segment for Ku and Ka-band UAVs than for X-band UAVs. These costs savings rapidly multiply even further when the second-order effects of having an all-weather X-band UAV ISR/strike capacity are fully realized:

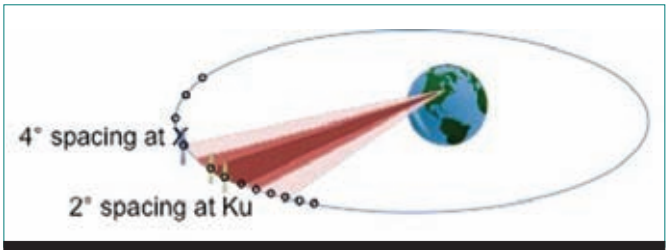

Figure 4: While X-band satellites are spaced at least 4° apart, commercial satellites are typically spaced 2° apart. This difference in spacing allows X-band terminals to operate at higher, more efficient spectral densities. Higher spectral power densities allow small, X-band antennas to transmit at greater efficiencies and throughput – even 2.5x greater than Ku-band on HTS.

"X-band's extreme resistance to rain attenuation is matched by its extreme resistance to attenuation from sandstorms and airborne dust, both very real concerns in today's theatres of operation."

All-weather UAV operations allow our military forces to deter, disrupt and/or destroy a target more quickly, in any weather condition, and move more quickly to the next target set. This in turn preserves critical resources - and saves lives and combat power as well.

What many UAV operators, planners, and acquisition offices don't know, however, is that many countries, like the United States, Australia, Brazil, Canada, Denmark, France, Germany, Italy, Luxembourg, The Netherlands, New Zealand, Spain, and many others can save staggering amounts of annual O&M costs by purchasing and using X-band UAVs, because these countries have already invested in their own X-band military satellite communications (MILSATCOM) constellations. Recognizing this important strategic investment, an X-band UAV can fly without any additional bandwidth costs at all, saving millions of O&M costs each year, allowing their military to generate even more combat power on limited budgets. The Wideband Global SATCOM (WGS) constellation is openly available to US military commanders and the UAV units who support them – but only if they and the DoD acquisition chains and program offices who support them know about these important strategic satellite assets.

The road ahead

Some DoD program offices have already taken advantage of X-band SATCOM. The US Navy's MQ-4C Triton UAV, for example, is a more capable, all-weather variant of the US Air Force's older RQ-4 Global Hawk. The UK's Protector UAV is a more lethal, all-weather X-band variant of the Sky Guardian/Certifiable Predator-B UAV. What is good for the goose is good for the gander: It would next be good to examine an X-band capability for the US Air Force's RQ-4 Global Hawk itself, as well as the US Army's MQ-1 Gray Eagle UAV, the US Navy's smaller MQ-8 Firescout and MQ-25 Stingray UAVs, and all non-program-of-record BLOS UAVs that are routinely contracted to provide services to the DoD, so each could finally take advantage of X-band's unique all-weather warfighting properties – at zero O&M cost for bandwidth.

Conclusion

The tech market over the last 30 years has reacted very favourably to products that reduce the size and weight, operational flexibility, or cost of a product or service. UAVs and, more broadly, SATCOM, is no different. SATCOM terminal manufacturers already recognize X-band's unique advantages and are producing smaller, lighter X-band terminals that deliver the performance that their go-anywhere, all-weather sensors provide, and that their go-anywhere, all-weather missions demand.

More broadly, X-band UAVs successfully exploit many of X-band's natural properties to provide an excellent option for warfighting commanders who demand all-weather, high-throughput performance and greatly increased operational flexibility. While doing so, X-band UAVs operate more efficiently and can significantly lower the DoD's O&M costs, helping the DoD to sustain and generate even more combat power, save lives, and accomplish the mission – even in the harshest weather conditions on the planet. **GMC**