In the mid-1980s, Hughes Network Systems introduced the first commercial very small aperture terminal (VSAT) network. Since then, Hughes has maintained leadership in satellite networks and services, manufacturing and shipping more than 7 million terminals to customers in more than 100 countries. The HughesNet® high speed satellite internet service now serves more than 1.4 million subscribers in the Americas, making it the world’s largest such network. This article describes the elements of a geosynchronous Earth orbit (GEO) satellite-based network providing broadband internet access and the design considerations to ensure high user availability.

The increasing demand for high speed internet service necessitates more satellite capacity to serve rural and underserved areas of the globe. With a finite number of orbital slots available, each satellite must have as much data capacity as possible while maintaining functionality. The first VSAT networks used leased transponders from multiple conventional satellites, and each satellite provided approximately 1 Gbps capacity. In 2007, Hughes launched SPACEWAY® 3, which provided 10 Gbps. Hughes launched EchoStar® XVII (JUPITER™ 1) in 2012, followed by EchoStar XIX (JUPITER 2) in 2017, providing 100 and 220 Gbps, respectively. The next satellite in the series will be EchoStar XXIV (JUPITER 3), planned for launch in 2021, which will achieve more than 500 Gbps.

SYSTEM ELEMENTS

The JUPITER System encompasses satellites, gateway stations and ground processing to provide connectivity to the internet; terminals to provide users connectivity; and infrastructure to manage and control the system. Significant advances in technology have enabled the capabilities of each to increase with each generation.

System coverage is provided via hundreds of spot beams from the satellite to users, served through gateway (GW) beams between ground stations and the satellite.
The JUPITER 3 satellite will provide broadband fixed satellite service (FSS) over the Americas using frequency segments at Ka-Band (26.5 to 40 GHz), Q-Band (33 to 50 GHz) and V-Band (40 to 75 GHz). The Q- and V-Band links will provide significantly more bandwidth to enable the higher capacity design of JUPITER 3, although operating at these frequencies poses challenges. For example, emissions in the 50.2 to 50.4 GHz band must be limited to protect the Earth Exploration Satellite Service (EESS). The narrow EESS band is bounded on both sides by the GW V-Band uplinks, creating a challenging filtering problem. The appropriate limit is being studied by the International Telecommunications Union (ITU)—ITU-R Working Party 4A—and will be proposed for adoption at the upcoming World Radiocommunication Conference 2019 (WRC-19), which will be held later this year in Egypt. To protect the EESS, WRC-19 will set the limits for FSS power levels in adjacent frequency bands, which will be implemented in the ITU regulations.

GW LINK TRADES

The use of the V- and Q-Band feeder links makes meeting the availability goals at the GWs challenging, given the higher atmospheric losses at these frequencies (see Figure 1).\(^1\) The gaseous attenuation at 50 GHz is 1.8 dB, compared to just 0.23 dB at 30 GHz. Rain further attenuates the signal (see Figure 2).\(^2\) For example, with a rain rate of 12.5 mm/hour, rain attenuation is 6 dB/km at 50 GHz compared to 2.5 dB/km at 30 GHz. Therefore, it is critical to place the GWs in a relatively dry region, ideally in rain regions B, D and E (see Figure 3).\(^3\) Convenient fiber backhaul is also a factor when deciding where to locate a GW, and the GWs need spatial isolation to minimize the amount of GW-to-GW satellite interference.

Despite placement of GWs in low rain regions, the link must accommodate a substantial amount of rain fade as well as increased free space path loss (FSPL), which increases as the square of the frequency:

$$\text{FSPL} = \left(\frac{4\pi df}{c}\right)^2$$  \hspace{1cm} (1)

where FSPL is a ratio, d is the distance, f the frequency and c the speed of light. The gain of each antenna, both satellite and ground, also increases as the square of the frequency, f:

$$G = k\left(\frac{\pi Df}{c}\right)^2$$  \hspace{1cm} (2)

where G is the gain (a ratio), D the antenna diameter, k the antenna efficiency factor and c the speed of light. Since there are two antennas in the GW link, as frequency increases, one antenna's gain will increase to compensate for the FSPL increase, and the other antenna's gain will at least partially compensate for the increased loss from rain.

It may seem that the higher antenna gain can be used to reduce antenna size at these higher frequencies; however, the higher gain is needed to overcome the higher atmospheric loss. One alternative is to increase the output power of the GW and satellite power amplifiers (PA). Unfortunately, with satellite power being such a precious resource and the PAs in the user equipment already as large as practical, to reduce user antenna size, another solution is needed.

One option is a parabolic antenna. The performance of a parabolic antenna is, in part, determined by the manufacturing accuracy of the reflecting surfaces. Ruze's equation predicts the loss of gain in an antenna due to RMS surface imperfections as:

$$\Delta G = -685.81\left(\frac{\epsilon f}{c}\right)^2$$  \hspace{1cm} (3)
where $\Delta G$ is the change in gain in dB and $\epsilon$ is the RMS surface imperfection. As $\Delta G$ is proportional to $f^2$ for constant surface accuracy, at higher frequencies the surface roughness can become a significant limitation. Some of the “extra gain” of the antenna at the higher frequency is degraded by the increased surface roughness.

ENSURING AVAILABILITY

The end-to-end links are designed to have most of the noise plus interference contributors on the user side of the link. Uplink power control is used at each GW to reduce the interference from an unfaded GW uplink into a separate, faded GW uplink, with only a small impact to the clear sky end to end. At higher levels of rain attenuation, rain loss only up to a certain point. The end-to-end C/N degrades as soon as the fade at the PGW has been exhausted, the GW switches to the diversity GW (DGW). The DGW switches back to the PGW once the fade at the PGW has subsided. A disadvantage of the $N+P$ scheme: it requires $N+P$ GW spot beams and GWs, with a switch matrix and switching algorithms on the satellite.

The availability achieved with $N+P$ diversity depends on the network size and number of redundant GWs. Figure 4 plots the probability of a user outage versus GW availability and diversity, showing the improvement achieved with up to two redundant GWs. With no redundancy, the availability of a user equals the availability of a GW; adding redundant GWs, the availability improves significantly.

Q/V-BAND COMPONENTS

Another challenge using Q- and V-Band spectrum is the availability of commercial and space-qualified TWTA amplifiers (TWTA). The satellite transmits to the GW at Q-Band, and the GW uses V-Band. On the satellite, power is precious, so the efficiency of the TWTA is a key requirement. These emerging components have lower efficiency than their more mature Ka-Band cousins; however, because the total power required for the Q-Band feeder links is a relatively small fraction of the total satellite power consumption, this efficiency shortfall is not a major problem. Improved efficiency will enable greater capacity in the future. At the GW, TWTA efficiency mainly affects system cooling and operating costs and is not as critical.

The GW feed represents another design challenge. For any given bandwidth, the Bode-Fano criterion establishes the reflection coefficient limit that can be achieved with a matching network, including a feed design, and, hence, the losses incurred. Although using as much spectrum as possible in the feeder links is desired, covering the Ka-Band receive signal below 20 GHz to the top of V-Band at 51.4 GHz is more than an octave and implies a feed with multiple sections—complicating the design and incurring excessive loss. A reasonable compromise between the bandwidth to the feeder links and complicating the feed design is using only a Ka-Band uplink around 27.5 GHz with Q-Band downlinks and V-Band uplinks to ~51.4 GHz—a span of 0.93 octave.

The JUPITER System VSATs have benefited greatly from improvements in technology. The first designs consisted of multiple printed circuit boards containing microprocessors, modems, frequency converters and discrete RF components. Today’s VSAT has been reduced to a system on a chip (SoC) with a handful of components, including GaAs MMICs. The RF components operating at 30 GHz are assembled in surface-mount packages and manufactured on high speed, automated
OUTLOOK

For more than 30 years, the demand for satellite-based internet connectivity has been increasing, measured both at an individual terminal and aggregating all satellite terminals. This demand drove the industry to increase the capabilities of GEO satellites to achieve higher data densities (Gbps/square mile) and now to develop constellations with hundreds to thousands of satellites in low Earth orbit (LEO), which will provide ubiquitous coverage and low transmission delay. These LEO constellations require the ground terminals to track the moving satellites, a similar problem for mobile terminals tracking GEO satellites. This mobility will require VSATs to adopt low cost phased array technologies or other steering mechanisms. The future satellite-based network could evolve as a hybrid, with both kinds of satellite systems providing the service optimal for each.

As data rates continue to increase, the demand for more spectrum will increase. The next band designated for FSS after V-Band appears to be E-Band (71 to 76 and 81 to 86 GHz). To use this spectrum will require developing new components that are available in commercial quantities with reliability comparable to today’s Ku- and Ka-Band components. Regardless of the assembly lines. Today, VSATs can receive greater than 1 Gbps on a single carrier using DVB-S2x codes. Adaptive coding and modulation techniques allow the system to provide the highest throughput the link will allow to individual users, while maintaining connectivity to severely disadvantaged users. Figure 5 shows a typical indoor modem and outdoor unit.

Fig. 5 Hughes satellite router (a) and outdoor unit (b).

References