Ground Based DVB-S2 Repeater for GEO Satellites

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Abstract

In 2018 Es'Hail-2, the first satellite to provide Amateur Radio Service from Geostationary Orbit will be launched from Florida. The satellite's narrowband and wideband transponders will cover about 1/3 of the globe. Most two-way amateur to amateur communication will take place through the satellite's narrowband linear transponder. This paper explores means to expoit the satellite's wideband transponder to provide two-way digital voice communications with the aid of a DVB-S2 repeater located at a relatively large earth station on the ground. This mode could provide digital voice and data service between modestly equipped stations while paving the way for the digital satellite based repeaters that are planned for future AMSAT satellites.

1. Introduction

In 2018 the Qatar Satellite Company's Es'hail-2 Satellite(ESHAILSAT, 2015) will be launched into geosynchronous orbit at 26°E Longitude. In addition to its Ku and Ka transponders providing commercial service to the Middle East and North Africa, Es'Hail-2 will carry a pair of transponders operating in the Amateur Radio Satellite Service bands. Through a collaboration between the Qatar Satellite Company, the Qatar Amateur Radio Society and AMSAT-DL, Es'Hail-2 will provide the first AMSAT Phase 4 (Geosynchronous Orbit) capability.

The Mitsubishi Electric Company built satellite carries a pair of transponders that will be dedicated for Amateur Radio Satellite Service use. Both transponders have 2.4GHz uplink and 10.45GHz downlink with global[1] beams. Both transponders operate in conventional bent pipe configuration. The so-called wideband transponder has a bandwidth of 8MHz and the narrowband transponder has a bandwidth of 250kHz. The narrowband linear transponder will support operation in traditional narrowband analog and digital modes. The wideband linear transponder is intended to support up to 2 or 3 DVB-S2 carriers for digital television and experimental digital modes.

While analog modulations e.g. SSB can provide usable communication, there are many advantages to using digital modulations. Digital modulations have all but replaced analog in most commercial applications. Es'Hail-2's wideband transponder is intended primarily for digital television but will also be available for experimentation with digital modes. One avenue for such experimentation involves means for improving the performance of small stations through the use of a larger station as a digital repeater.

This paper explores a digital repeater concept using the combination of digital modes and a DVB-S2 ground based repeater which multiplexes multiple channels onto a single DVB-S2 downlink. The repeater is intended to provide more cost effective communications between two modest earth stations than would otherwise be possible. The ar-

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[1]A global beam provides approximately 160°coverage at the equator.

chitecture of the concept is similar in some respects to the US Military's Mobile User Objective System (MUOS)(Oetting & Jen, 2011), which is also based on ground based digital repeaters.

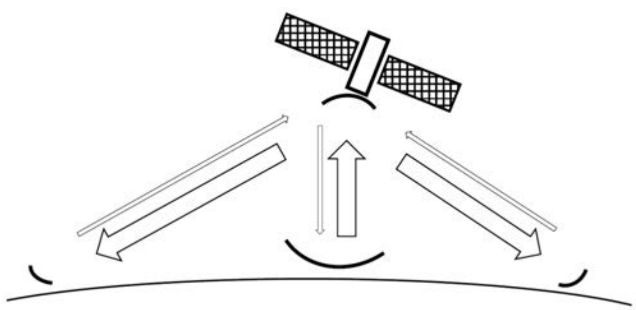

Figure 1. Link Configuration

2. System Configuration

The configuration of the various satellite links for digital repeater operation is illustrated in Figure 1. The wide arrows indicate wideband links. The narrow arrows indicate the narrowband links. The DVB-S2 repeater is the larger antenna. Note that the small earth stations in this configuration need only receive the wideband DVB-S2 while transmitting only a narrowband signal. The large earth stations receives all narrowband transmissions, demodulates all of the data, and re-transmits the data in a DVB-S2 carrier. The small stations are thus able to receive all data from all active transmitters that are demodulated by the repeater.

3. Communication System Performance

There are many factors that determine the performance of a satellite based communication system. The following sections provide a brief introduction using a very simplified model that may help explain the repeater concept.

3.1. Transmitter Performance

A simplified metric for the performance of the transmitting system is EIRP (Effective Isotropic Radiated Power). EIRP is the total signal power being radiated in a particular direction. This is determined by the output power delivered to the antenna and the gain of the antenna in a particular direction. The power delivered to the antenna is the output power of the amplifier reduced by the losses between the amplifier and the antenna.

EIRP will normally be highest at the beam center and will be generally be 2 or 3dB lower at the edge of coverage (EOC). EIRP is normally expressed in units of dBW. Note that EIRP is the total power of all carriers. When there are multiple carriers in a single transponder, the EIRP of each individual carrier will be lower.

The EIRP of the 10.5GHz wideband downlink from Es'Hail-2 is expected to be about 31dBW at EOC. The LTWTA (Linearized Traveling Wave Tube Amplifier) output is 140 Watts (21.5dbW) and will be operated at 6dB backoff with approximately 1.5 dB of on-board losses delivering 14dbW to the antenna. The Global Horn Antenna provides approximately 17 dBi of gain at EOC resulting in a maximum EIRP of 14dBW + 17 dB = 31dBW at EOC. The 6dB backoff keeps the interference from the modulation products of the multiple carriers to acceptable levels.

3.2. Receiver Performance

A simplified metric also exists for the performance of a satellite receiving station. This is known as G/T. This number can be used to directly compare the performance of different receiving systems. G/T encompasses the gain of the receive antenna and the noise associated with both the antenna and the front-end amplifier sections of the receiving system. G/T is the ratio of the antenna gain (G) to the system noise temperature (T). G/T has units of 1/°K where K is degrees Kelvin.

For a parabolic dish antenna, gain is mostly a function of the antenna size. Doubling the diameter increases the gain by approximately 6dB. The noise temperature is determined by both the background noise that is picked up by the antenna and the internal noise generated within the amplifiers. Modern low noise amplifiers (LNA) provide excellent performance at relatively low cost. The amplifier performance, however, is ultimately limited by the thermal noise in the electronics. At higher antenna elevation angles, the noise factor of the LNA is the dominant factor in system noise temperature. For stations near the edge of the coverage area, the lower elevation angle results in increased noise from the relatively high noise temperature of the Earth. At very low elevations this Earth noise pickup becomes the limiting factor for G/T.

A 60cm dish operating at 10.5GHz will have a G/T on the order of 14dB/°K. Doubling the dish size to 1.2m will increase this to about 20dB/°K. Doubling again to 2.4m will increase the G/T to about 26dB/°K. For most users of Es'Hail-2, a 90cm dish will be typical with a G/T of about 17dB/°K. In a subsequent section we will see how much difference this makes in system performance.

The G/T at the satellite is significantly lower. This is due to the much lower gain of the global beam horn antenna and the relatively high noise temperature of the Earth, which fills the aperture. For Es'Hail-2, the G/T at the EOC will be about -12dB/°K.

3.3. Path Losses

Geosynchronous orbit is at 35.8km above the equator. The distance from an Earth station to a satellite depends on the slant range to the satellite which in turn depends on the elevation angle. This ranges from 35.8km at the equator to about at the 41.7km at the horizon. The path loss is a function of both frequency and distance. For 10.45GHz downlink this is about 204dB to 205dB. Since pathloss is a simple ratio it is dimensionless.

3.4. C/N

The "quality" of a signal over a communication channel can also be expressed by a single metric known as Carrier to Noise ratio or C/N. This is the power of the carrier divided by the power of the noise in the receiver bandwidth. C/N falls as we increase the bandwidth of the receiver. This is because while the power of the carrier doesn't change, proportionately greater noise power is within the larger bandwidth which lowers the C/N. Doubling the bandwidth will double the noise power which reduces the C/N by 3dB. Like pathloss, C/N is a dimensionless ratio.

The "required" C/N for a particular kind of modulation depends on both the modulation type and, for digital signals, the gain that may achieved by coding. State of the art codings, e.g. those used in DVB-S2, can allow operation where the signal is actually below the noise.

With figure of merits for the Transmitter (EIRP) and receiver (G/T) we can calculate the C/N for a given path loss and bandwidth from the following equation.

$$\begin{aligned} C/N = EIRP + G/T - PATHLOSS \\ +228.6 - 10 * Log_{10}(Bandwidth) \end{aligned} \quad (1)$$

The 228.6 term in the above equation is the inverse of Boltzmann's constant which has units of Hz°K/dBW. Boltzmann's constant relates effective temperature and noise power in 1 Hertz.

The units for the above equation are:

$$W * \frac{1}{^\circ K} * \frac{Hz * {}^\circ K}{W} * \frac{1}{Hz} \quad (2)$$

All units cancel producing a dimensionless ratio.

With the above introduction we can now discuss the specific links possible with Es'Hail-2.

3.5. Wideband Downlink

In the proposed digital repeater concept, a single DVB-S2 (ETSI, 2014), carrier operating in the 10.5GHz wideband downlink would digitally multiplex all of the individual uplink signals. This carrier would originate from a single earth station. The nominal symbol rate would be 1 MBaud or above to maintain compatibility with the low end range of DVB-S2 receivers. This DVB-S2 carrier would share power with all other carriers operating in the wideband transponder. Assuming use of 1/4 of the available power, the downlink EIRP at EOC would be about 25dBW.

A 90cm receive system with a G/T of 17dB/°K would realize a C/N of 25 + 17 + 228.6 - 205 - 61.3 = 4.3. This is more than sufficient for DVB-S2 QPSK with rate 1/2 FEC providing an aggregate Quasi Error Free data rate around 1 Mbps.

4. Wideband Uplink

The wideband uplink DVB-S2 carrier from the large Earth station would nominally employ a 2.4m antenna. Operating at 2.4GHz, the path loss at S band drops to 192dB. The G/T of the receiver at the satellite is -12dB/°K. The transmit gain is about 34dB which added to a nominal output power of 100 Watts (20dBW) results in an EIRP of 54dBW. The resulting C/N for a 1.35 MHz bandwidth would be 54 -12 +228.6 -192 -61 = 17dB which is more than required. The uplink power level would be controlled and backed off as appropriate for sharing the downlink power with other stations using the wideband transponder. The wideband DVB-S2 carrier from the repeater would be similar to any other wideband DVB-S2 carrier sharing the transponder except for symbol rate and modcodes.

5. Narrowband Transponder Uplink

The Narrowband transponder is designed primarily for analog modes in 2.5 kHz channels. These are intended to be used station to station. Use of the narrowband transponder requires a narrowband receiver.

It is possible to transmit a narrowband digital waveform in the channel that can remain within the 2.5 kHz bandwidth. Using QPSK with a 1.8kHz carrier, approximately 3.6kbps of raw digital throughput is possible. This is sufficient to carry frames of low-bit rate compressed digital speech, e.g. 1300bps Codec2 (Rowe, 2011) allowing for additional overhead and some redundancy. It should be noted that while DVB-S2 in the downlink provides Quasi Error Free performance with an extremely low bit error rate, which is necessary for digital television and IP, this is actually overkill for digitized voice. Digital voice is relatively insensitive to frame error rates as high as a few percent. Uncoded QPSK with a C/N on the order of 7dB should therefor be practical for low bit rate compressed voice.

Using a 90cm dish with 2W (3dBW) at the antenna the uplink EIRP is approximately 28dBW. The path loss at 2.4GHz is about 193dB. At the EOC the satellite has a G/T of -12dB/°K. For a bandwidth of 2.5kHz the C/N at the satellite is 28 -12 + 228.6 - 193 -34 = 17.6dB.

6. Narrowband Transponder Downlink

For the narrowband transponder the downlink power is shared by approximately 50 channels which results in an EIRP per channel at EOC of 14dBW (31 - 17). For the 2.4M station, the downlink C/N in this case is 14 + 26 +228.6 - 204 - 34 = 30.6 dB. The downlink thus adds little additional noise to the system and the centralized receiver sees a C/N close that of the satellite, i.e. about 17 dB.

For the 90cm Earth station, the G/T is about 9dB lower resulting in a C/N of 21dB.

7. Using Narrowband Digital with the Wideband Transponder

As the wideband transponder is also linear, it is possible to use it for narrowband digital signals as well. Such sharing would be difficult with analog signals due to the need for careful control of uplink power levels to prevent saturation and other difficulties with frequency accuracy and interference. However, with digital repeater modes it is possible to incorporate automatic power controls in the digital protocols used to gain access. The use of channel acquisition protocols can also reduce the potential for interference from non-conforming stations by only granting access to stations with signals that conform to the requirements.

7.1. Downlink C/N

If approximately 1/4 of the transponder's output power (after backoff) is devoted to narrowband uplinks, then 25 dBW would be available for use by all of active narrowband digital downlinks at EOC. With 80 channels of 25kHz each, 6dBW would be available for each of the narrowband digital carriers. The downlink C/N at the 2.4m station in this case would 6 + 26 + 228.6 -205 -44 = 11.6 dB for 25kHz bandwidth carriers. This is sufficient to support QPSK even with light or no coding. Note that the C/N received by a 90cm Earth station would be about -9dB lower (2.6 dB) and unusable for uncoded or lightly coded QPSK.

7.2. Uplink C/N

The uplink C/N from a 90cm dish transmitting with 4W would be about 10.6dB at 25kHz bandwidth. In 12.5kHz, a 2W carrier would provide the same 10.6dB. Even a 12.5 kHz digital carrier can provide more than 10kbps for digital speech allowing for higher voice quality than possible in 2.5kHz channels. The single multi-channel receiver at the repeater would be able to accommodate different bandwidths within a basic 25kHz channel spacing.

Note that the 80 25kHz wide channels would occupy a total of 2 MHz, or 1/4 of the total wideband transponder bandwidth of 8MHz. With digital protocols, large numbers of users could be accommodated using a combination of statistical multiplexing and automated handoffs.

It should be noted that only the single repeater receiver needs to demodulate the narrowband digital signals. Since all of the demodulated data is relayed over the multiplexed DVB-S2 link, narrowband receive equipment is not required by the smaller stations. A single low cost DVB-S2 receiver can thus support all digital modes from speech to high definition video. The potential elimination of the narrowband receive equipment results in a more economical system.

The narrowband digital receiver of the repeater is an expensive piece of equipment. However, it is very similar in function to the regenerative repeaters in development for the Phase 4B project. The difference is that the equipment for use in a ground based repeater does not need to be space qualified and can be implemented mostly with off the shelf SDR hardware combined with specialized software similar to that being developed for Phase 4B.

8. Latency

The use of a ground based repeater does results in two round trips to the satellite instead of one. This introduces an inherent delay of about 480ms or half a second compared to usual satellite delay of 240ms. The satellite transponder adds minimal additional delay. However, the DVB-S2 decoding of the multiplexed uplinks adds additional delays on the order of 100ms bringing the total station to station delay to about 600ms. The added DVB-S2 delays can be reduced to about 50ms by increasing the symbol rate to 2MBaud. This has about 3dB impact on the downlink C/N. Methods are also potentially available to reduce this delay somewhat for lower symbol rates. (Ritchie, 2017).

9. DVB-S2

The use of DVB-S2, especially its VCM (Variable Coding and Modulation) and GSE (Generic Stream Encapsulation) features provides opportunities for combining multiple data streams in a single downlink carrier. VCM allows stations with different G/T performance to receive streams with different Modulation and Coding. For example, QPSK FEC 1/4 frames can be received by stations with small dishes while 32APSK frames with 9/10 coding are received by stations with large dishes. The efficiencies range from .5 to 4.5 for a 1MBaud symbol rate. The corresponding Quasi Error Free bit rates can range from 500kbps to 4.5Mbps. The use of GSE allows a single carrier to provide a GSE stream carrying the multiplexed narrowband uplinks together with an mp4 video stream originating at the same location as the repeater.

Using VCM and GSE requires appropriate capability in the DVB-S2 receiver. These features are already appearing in commercially available devices. In addition, low cost DVB-S2 receivers for Amateur Radio use are in development.

10. Power Control

For shared use of a transponder, some means of controlling the uplink power of the individual stations is required in order to keep the total output of the transponder below the compression point. If this is not controlled, the resulting intermodulation products will destroy all signals. This is particularly important where there is no AGC control in the satellite. Any power from a station which is in excess of that necessary to close the link is either wasted power or the cause of interference.

For the narrowband transponder in Es'Hail-2, power control is somewhat managed essentially by jamming signals that have too much power in order to cause the individual operator to reduce the power. It remains to be seen how well this approach will work in practice, especially near saturation. The narrowband transponder is equipped with an AGC function which helps to avoid overload.

The wideband transponder in Es'Hail-2 has no AGC function. It is intended primarily for use for Digital Television with just 2 or 3 carriers. The frequency and power levels for these carriers would have to manually coordinated. This is similar to the case for commercial VSAT operation.

In order to use the wideband transponder for handling a large number of narrowband digital carriers, effective means of power control is absolutely required. Essentially, each station is capable of transmitting with the power necessary to close the link under all conditions (including rain which impacts the uplink). The station, however, backs off from this level to provide just enough power to close the link. This back-off is controlled by the repeater which is monitoring the signal level of each individual channel as well as the combined power in all channels.

10.1. Channel Access Protocol

For a practical digital repeater system it is usually necessary to have a Channel Acquisition Protocol by which an Earth station acquires one of the uplink channels of the satellite. Several of the uplink channels can be used for this protocol depending on the number of currently available channels. According to some set of protocol rules, individual stations are allowed to transmit a short burst in one of the channels at a randomized time based on the station's callsign. The burst may be on the order of 100ms allowing bursts from 10 different stations per CAP channel per second. All stations monitor the downlink data and are only allowed to transmit a CAP burst if they are properly locked to the downlink and decoding the aggregated downlink data. The repeater monitors the CAP channels and if it correctly receives a burst from a particular station, it temporarily allocates an available uplink channel to the station. The allocation also provides an initial power level for the station, relative to the power it provided in the burst. Thereafter, carrier power control occurs on a continuous basis during active transmission.

There always exists the possibility that two or more stations may collide with their CAP bursts. In that case, the repeater receiver cannot demodulate a valid signal. The fact that a collision occurred in a particular time-slot can be noted in the downlink data. Randomization techniques can then be used to separate the retries from each other. Similarly, if a signal is above the noise but otherwise impaired (e.g. in frequency offset), that fact can be noted in the downlink data. Specials channels and protocols could also be provided to support stations being placed into service for the first time. These channels could provide additional instrumentation useful for test and troubleshooting.

Using a CAP, access to the repeater is no longer un-coordinated. The repeater is open, but the rules for access have to be strictly followed to acquire a channel. Stations not following the rules are considered to be creating intentional interference. Fortunately, the application software of the radios will be carrying out the protocols automatically and the operators would not need to be involved in the details.

11. Phase 4B

Future Amateur Satellites are in development that are based on deploying the digital repeater at the satellite instead of on the ground(Thompson, 2016). This would halve the delay associated with the two round trips. Locating the actual receiver at the satellite also allows operation of the uplinks at somewhat lower C/N since there is no need to relay the narrowband signals to ground. Other than the additional delay, operating the Es'Hail-2 wideband transponder through a ground repeater can be very similar to a satellite based repeater. This can provide much experience useful in the development of future AMSAT Phase 4 payloads.

12. Worldwide Coverage

Unfortunately, Es'Hail-2 will not be accessible to 2/3rds of the globe. This leaves the Americas (except for eastern Brazil) and most of the far east outside of the party. However, if two or more similar satellites are eventually deployed to suitable positions, it would become possible to provide worldwide coverage through the repeaters. Stations in Brazil, Singapore, and Hawaii for example, might each be able to receive the downlinks from two satellites and uplink to both. Any station would thus be able to receive the narrowband uplinks from stations anywhere on the globe.

13. Conclusions

Es'Hail-2 promises to be a game changer for Amateur Radio providing continuous reliable 24/7 communication among amateur radio operators in its coverage area. The ability to support the traditional analog modes e.g. SSB, CW, and PSK has much appeal. However, as discussed above, there is much to be gained by moving to full digital repeater operation. This could be handled entirely within the wideband transponder without impacting any of the operations on narrowband transponder. The advantages potentially available from digital repeater operation seem well worth the effort of further exploration.

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