Performance of GBS over WGS1, 2, 3 using DVB-S and DVB-S2

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The Wideband Global System (WGS) is currently operational in the Pacific Ocean using WGS1 (175E). GBS traffic is supported in that theater today using the Digital Video Broadcast by Satellite (DVB-S) and operates using terminals originally designed for operation using the UHF Follow-On satellite (UFO8). These terminals can now operate over WGS1 and UFO8. GBS is planned to migrate to the JIPM in 2010. The Joint IP Modem (JIPM) will use the second generation DVB-S2 which represents a quantum leap in capability over DVB-S in terms of its power and bandwidth efficiency. Further the JIPM allows hub-spoke operation between a control center at a Teleport and the remote terminals equipped with a remote Modem.

This paper will address the data rate performance of GBS terminals using the current DVB-S and the JIPM DVB-S2 over WGS1 (175E), WGS2 (60E) and WGS3 (12W). First, a reference link is defined based on the Next Generation Receive Terminal (NGRT). Next data rates will be determined for the reference link based on WGS measured WGS1 data. Finally global availability maps will be determined for the reference link when operating globally over WGS1, WGS2 and WGS3 using WGS Ka-band beams.

I. INTRODUCTION

WGS1 is currently operational and supports the Global Broadcasting System (GBS) today using DVB-S. WGS2 and WGS3 are planned for initial operations in 2009 and 2010 respectively. There are in excess of 600 GBS terminals today with other terminals being planned. This paper confines itself to the Next Generation Receive Terminal (NGRT) [1]. These terminals are capable of receiving dedicated GBS broadcasts as well as the forward link of the Return Channel by Satellite (RCS) system [1, 2, 3] which currently uses DVB-S. Both the GBS and the RCS systems plan to migrate to DVB-S2 using the JIPM around 2010.

This paper will determine the optimum performance for DVB-S and DVB-S2 for a reference link using WGS as well as DVB-S and DVB-S2. WGS Ka-band beams have different EIRPs and different number of 125 MHz channels per beam. Two GBS carriers are assumed per WGS 125 MHz channel. WGS has eight spot beams and two area beams. Beam EIRPs are taken from measured values on WGS1.

GBS link performance will depend on the actual beam placed on the NGRT terminal. This paper will consider two disadvantaged spot beams (low EIRPs) and one area beam taken from a previous beam and frequency plan [1]. In addition both DVB-S and DVB-S2 Modems are considered for a total of six cases. The design objective is a data rate of 45 Mbps for the spot beams and as large as possible for the area beams. The design approach equates the power-limited data rate to the bandwidth-limited data rate for the reference link.

Finally, reference link availability results are extended globally using an ITU-based propagation mapping shell [4]. The global maps are shown for selected cases. Each map shows the quantized color-coded availability from each satellite's field of view based on the optimized data rate for the reference link which operates in a relatively benign propagation environment.

II. WGS

WGS1 parameters have been measured for the Narrow Coverage Antenna (NCA) and Area Coverage Antenna (ACA) beams. The beams have a different number of shared 125 MHz channels with the targeted channel having 2-GBS carriers. The EIRP (dBW) per GBS carrier is:

Beam	EIRP, dBW	PSF	PR	EIRP/Car
NCA5	58.4	6	0.3	52.1
NCA7	60.1	9	0.3	50.8
ACA1	42.8	0	0	42.8

The power sharing factor (PSF) (in dB) accounts for the sharing of the beam power among the channels as well as the assumption of two GBS carriers per targeted channel. Power Robbing (PR) is caused by the sharing of the High Power Amplifier (HPA) power among the beam signals, the uplink noise and the generated inter-modulation products.

III. NCA REFERENCE LINKS

The reference links will be from a Teleport to a WGS satellite and then to a NGRT terminal using the chosen NCA beam. WGS1 Beginning of Life (BOL) values will be used for all three satellites.

Link Analysis

The limiting links are “clear sky” on the uplink and “rain” on the downlink. It is assumed that the NCA1 beam is centered on the Teleport and the NGRT is at the edge of the targeted downlink NCA beam. The link budgets are shown in Table 1:

	DVB-S2	DVB-S	DVB-S2	DVB-S	
	NCA7BOL	NCA7 BOL	NCA5 BOL	NCA5 BOL	
# of down-link channels	4	4	2	2	
terminal EIRP up (dBW)	85	85	85	85	Linear
power sharing factor	8	8	8	8	Uplink Sharing
carrier EIRP up (dBW)	77	77	77	77	
prop loss	3.3	3.3	3.3	3.3	Clear Sky
other losses	0.9	0.9	0.9	0.9	Fixed Losses
free space loss	214.2	214.2	214.2	214.2	14 deg, 30.5GHz
satellite G/T	13.8	13.8	13.8	13.8	Off Peak
up C/No	101	101	101	101	
beam EIRP	60.1	60.1	58.4	58.4	BOL
power sharing factor (dB)	9.0	9.0	6.0	6.0	Multi-Chan, 2-Carr
power robbing (dB)	0.3	0.3	0.3	0.3	up noise,Ims
carrier EIRP down	50.8	50.8	52.1	52.1	GBS Carrier
prop loss	6.75	4.3	7.9	5.37	Supportable Loss
other losses	0.9	0.9	0.9	0.9	Fixed
free space loss	210.4	210.4	210.4	210.4	35deg,20.7GHz
terminal G/T	17.83	18.38	17.68	18.1	Degraded G/T
down C/No	79.1	82.1	79.2	82.1	
C/No for IM	103	103	103	103	
C/No for other	500	500	500	500	
net C/No	79.1	82.1	79.1	82.0	
burst info rate	45.34	46.08	45.34	46.08	Rb (Mbps)
available Eb/No	2.5	5.4	2.5	5.4	
required Eb/No	2.54	5.4	2.54	5.4	
margin	0.0	0.0	0.0	0.0	
net transport rate	45.10	45.10	45.10	45.10	R (Mbps)
mod code #	2	2	2	2	
inner code	2/3	2/3	1/2	2/3	
overall code rate	0.6144	0.6144	0.4950	0.6144	
Rs	36.90	37.50	45.80	37.50	
BW	47.60	48.38	59.08	48.38	
Propagation loss per beam	6.75	4.3	7.9	5.37	

Table 1: Spot Beam Budgets

The budgets are provided for NCA5 and NCA7 which are the most disadvantaged for GBS presented in reference [1]. Only BOL values are considered and both DVB-S and DVB-S2 are presented. The design point is 45.1 Mbps data rate. All links are downlink limited.

DVB-S Links

The burst rate, Rb, is defined for DVB-S as the transmission rate including the MPEG-2 framing. The user rate is indicated as the net transport rate and is obtained from the burst rate by multiplying by 184/188. symbol rate of 37.5 Msps which results in an occupied bandwidth of 48.4 MHz for a 1.29 rolloff factor.

The power and bandwidth requirements will vary with the DVB-S inner code as (the Eb/No values assume a 1 dB channel loss [1]):

inner code	bits/sym	Eb/No (dB)	Rs Max	BW
1/2	0.92	4.9	37.5 Mbps	48.4MHz
2/3	1.23	5.4	37.5	48.4
3/4	1.38	6.1	37.5	48.4
5/6	1.54	6.8	37.5	48.4
7/8	1.61	7.4	37.5	48.4

The rate 2/3 inner code results in a bandwidth limited data rate of 45.1 Mbps for each GBS carrier. This rate is equated to the power-limited data rate with the supportable propagation losses of 4.3dB and 5.37dB for NCA7 and NCA5 respectively.

DVB-S2 Links

The power and bandwidth efficiencies for DVB-S2 are quite different than DVB-S2.Using the Joint IP Modem (JIPM) the DVB-S2 Modem capabilities [1] are shown below as:

inner code	bits/sym	Eb/No(dB)	Rs Max	BW (MHz)
1/2	0.99	2.54	48	62.4
3/5	1.19	3.04	48	62.4
2/3	1.32	3.19	48	62.4
3/4	1.49	3.57	48	62.4
4/5	1.59	3.99	48	62.4
5/6	1.65	4.33	48	62.4
8/9	1.77	5.02	48	62.4
9/10	1.79	5.17	48	62.4

Note that the JIPM is designed for DVB-S2 with a maximum symbol rate of 50 Msps; however only half the channel (124.8 MHz accounting for the sub channel overhead) is available for GBS [1]. Hence the maximum allowable symbol rate per carrier is 48 Msps.

Disadvantaged Spot Beam Capacities

The NCA5 data rate versus loss is shown in Fig. 1.

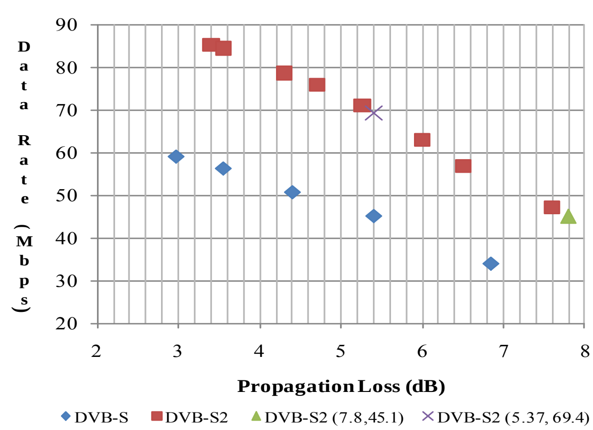

Figure 1: NCA5 Data Rate Vs Loss

The blue and red points correspond to S & S2 respectively at various inner code rates and are obtained by equating the power-limited and bandwidth-limited data rates. The DVB-S design point (5.4,45.1) can be achieved using DVB-S2 at (7.8,45.1) allowing 2.4 dB more propagation margin. Similarly, DVB-S2 will provide 69.4 Mbps for the same 5.4 dB margin (54% increase in capacity). Hence, DVB-S2 can provide a more reliable link for the same rate or more capacity for the same reliability.

The NCA7 data rate versus loss is shown in Fig. 2.

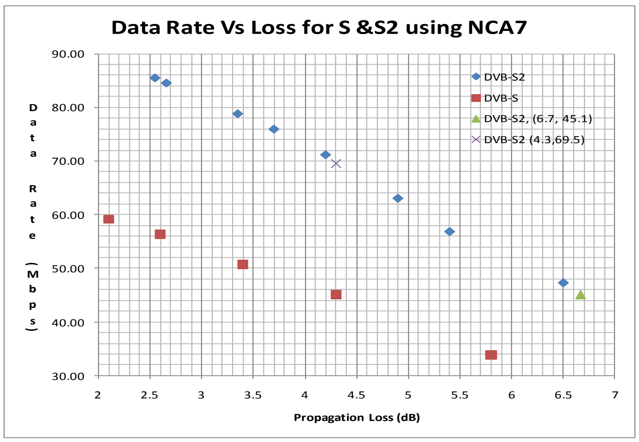

Figure2: NCA7 Data Rate Vs Loss

The DVB-S design point (4.3,45.1) can be achieved using DVB-S2 at (6.7,45.1) allowing 2.4 dB more propagation margin.Similarly, DVB-S2 will provide 69.5 Mbps for the same 4.3 dB margin.

IV ACA1 REFERENCE LINKS

Both ACA beams have almost the same EIRPs although ACA1 is slightly lower and will be used as the reference. The ACA1 reference links have a reduced uplink relative to the NCA case due to the required lower data rate. The same NGRT terminal will receive the links in the ACA1 beam. The link budgets are shown in Table 2 .

The EIRP per carrier is about 8 dB lower than for the NCA beams. This results in serverely power-limited downlinks for the two cases shown.

The user rate versus the inner code is shown in Fig. 3 below for the ACA1 beam.

prop loss	3.3	3.3	
other losses	0.9	0.9	
free space loss	214.2	214.2	
satellite G/T	13.8	13.8	
up C/No	94	94	
beam EIRP	42.8	42.8	ACA1 BOL
power sharing factor (dB)	0	0	Single Carrier
power robbing (dB)	0	0	
carrier EIRP down	42.8	42.8	
prop loss	3.5	3.5	
other losses	0.9	0.9	
free space loss	210.4	210.4	On the 34.9 deg contour
terminal G/T	18.66	18.66	
down C/No	75.26	75.26	
C/No for IM	500	500	No Intermods
C/No for other	500	500	
net C/No	75.2	75.2	
burst info rate	18.45	10.72	
available Eb/No	2.5	4.9	
required Eb/No	2.54	4.9	
margin	0.0	0.0	
net transport rate	18.35	10.49	75.4% increase using S2
mod code #	2	2	
inner code	1/2	1/2	
overall code rate	0.4950	0.4608	
Rs	18.64	11.63	
BW	24.04	15.00	

Table2: ACA1 Link Budgets

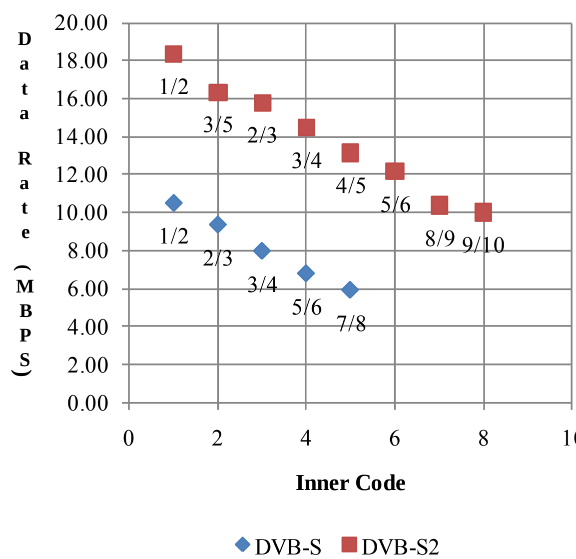

Figure 3: ACA1 Data Rate Vs Code Rate

The rate ½ inner code is the optimum code rate for both modems. The use of DVB-S2 increases the data rate by 75.4%. The major improvement results from the reduced power requirement (4.9-2.54= 2.36 dB) as well as a small improvement from the reduced framing overhead.

V GLOBAL AVAILABILITY MAPS

A "GBS Data Mapper" (GDM) [4] was developed for the Navy (PMW-176) in 1998. GDM computes the losses from the GBS-capable UFO satellites to each point in a grid defined under each satellite's footprint. The component losses (due to rain, clouds, and atmospheric gases) were computed using ITU-R statistical models and supporting climatological datasets, and summed using a model referred to as DAH [5]. A mapping shell allowed these losses (components and totals) to be plotted on a world map.

GDM has been extended to include GBS carriers operating over the WGS satellites. It has also been upgraded to exploit the popular "ITU-R Propagation Models Software Library" (better known as "propa.dll", [6]) created by the French *National Center for Space Studies* (CNES). Finally a terrain database was added so that estimates of station height could be supplied to the gas loss calculation.

<u>NCA 7</u>

NCA7 has the lowest EIRP per carrier of the 8 NCA beams. The global map in Fig. 4 shows the availability variation with location as viewed from the three WGS satellites (assuming all three use beam 7 at its specified EIRP of 49.4 dBW per GBS carrier).

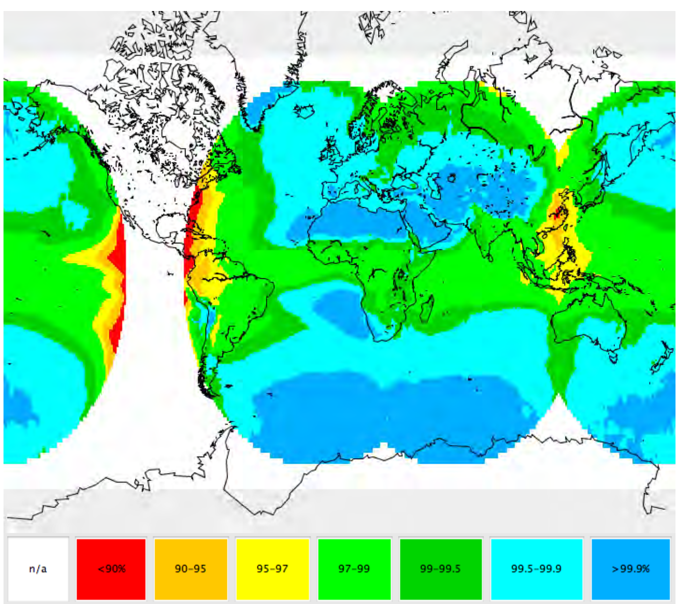

Figure 4: NCA7, DVB-S, R2/3, 45.1Mbps

The legend below Fig 4 will be the same for Figs 4, 5, 6 7 and 8. The blue regions have availabilities of at least 99.5%. Yellow, amber and red have low availabilities compared to most current GBS links. The green shades are in between but still acceptable. The global map in Fig. 5 is for the same design point but uses DVB-S2

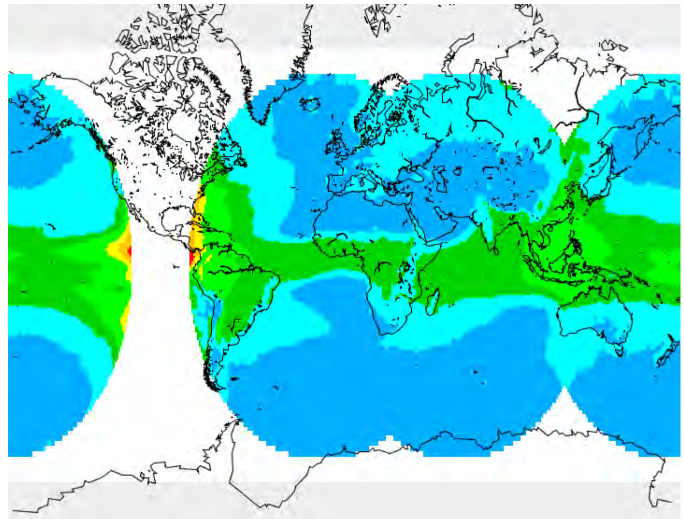

Figure5: NCA7, DVB-S2, R1/2, 45.1MBPS

The reduction in the poorer availability regions is evident when comparing Figs. 4 and 5.

If the propagation loss in the reference link is held constant at 4.3dB for DVB-S and DVB-S2 then the higher data rate using DVB-S2 (69.5Mbps) has the same availability map shown in Fig. 4.

<u>NCA5</u>

The availability map in Fig. 6 shows the availability regions for NCA5 using DVB-S at 45.1 Mbps.

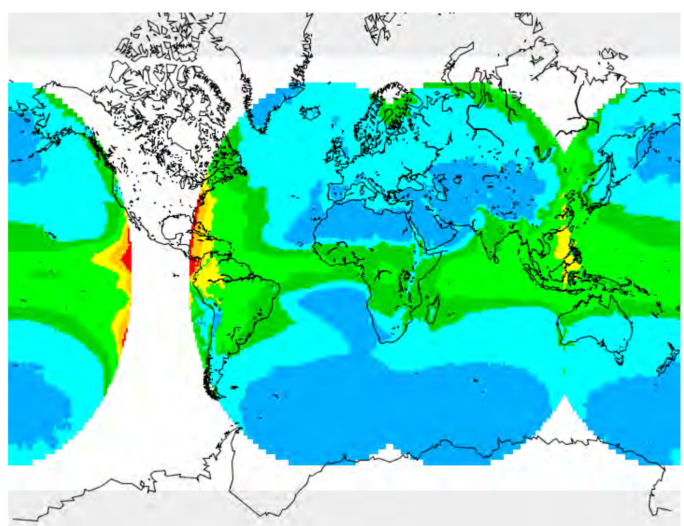

Figure 6: NCA5, DVB-S, R2/3, 45.1 Mbps

Comparing Figs. 4 and 6 shows the change in the availability regions as a consequence of the higher NCA5 EIRP per carrier of 1.3 dB.

Similarly, Fig. 7 shows the global availability map of NCA5 when using DVB-S2 instead of DVB-S at the same rate of 45.1 Mbps. The change in the availability

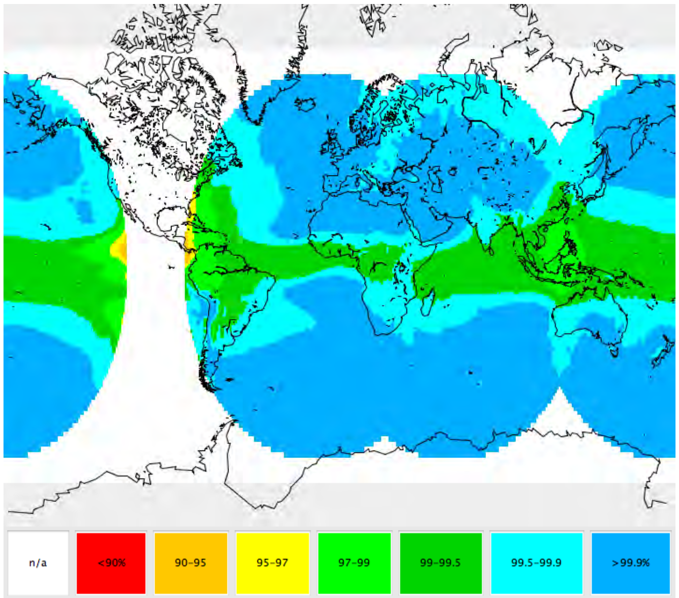

Figure 7: NCA5, DVB-S2, R1/2, 45.1 Mbps

due to the increased EIRP per carrier of beam 5 over beam 7 using DVB-S2 is evident from the Figures.

ACA1

The availability map using ACA1 is shown in Fig. 8.

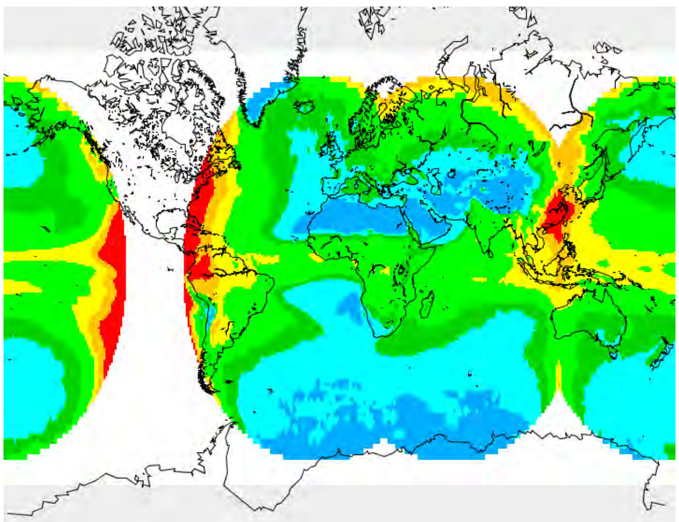

Figure 8: ACA1, DVB-S, R1/2, 10.5Mbps

This map also applies to DVB-S2, R1/2 operating at 18.4Mbps. This map shows larger regions with poor availabilities due to the relatively low loss of 3.5 dB in the reference link.

VI SUMMARY

This paper summarizes the performance of GBS using the first three WGS satellites. The performance is based in part on the measurements made on WGS1. A reference link is defined which includes the NGRT terminal as well as DVB-S and DVB-S2 Modems. The latter's performance is based on JIPM measurements. A major assumption is that targeted channel contains 2-GBS carriers. The other users in the beam share the remaining downlink channels and consequently the beam power (each channel shares the HPA power equally). The results are also applicable to hub/spoke VSAT systems (2-way) which would use either DVB-S or DVB-S2 in the forward direction [1].

The performance of the reference link depends on the actual beam used for that location. The beams are a heterogeneous mix so disadvantaged beams are used to assess performance. The reference link is expanded globally using the GDM applied to WGS. Supportable availabilities are then extended to the 3-satellite WGS constellation using the reference data rate of either 45.1 Mbps (spot beams) or 10.49 Mbps (area beams).

Spot Beams

Two beams and 2 Modems were considered. In one case the Modems were compared in terms of loss for the same data rate of 45.1Mbps as

	Loss: S	Loss: S2	Delta(dB)	%
NCA7	4.3	6.7	2.4	74
NCA5	5.4	7.8	2.4	74

Horizontally, the improvement in link reliability due to the use of the improved DVB-S2 Modem is 2.4 dB. Vertically, the loss improvement of beam 5 over beam 7 is 1.1dB (EIRP/carrier differs by 1.3dB). The 4 spot availability maps are shown for cases represented in the table. The improvement in availability is much more pronounced for the Modem change than the beam change in this instance as indicated in the maps.

The Modem performance for the same loss but different supportable data rates is

	Loss	Rate:S	Rate:S2	%
NCA7	4.3	45.1	69.5	54
NCA5	5.4	45.1	69.3	54

DVB-S2 can be used to increase the capacity for the same supportable loss (horizontal). The gain is 54% in this instance. In this case the availability maps are the same for both Modems using the same beams. (Once again beam 5 is superior to beam 7 by 1.1 dB in terms of supportable loss.)

ACA1 Beam

The reference links using area beams are severely power limited. Beam 1 is used in the following as it is slightly worst than beam 2 in terms of EIRP:

	Loss	Rate:S	Rate:S2	%
ACA1	3.5	10.49	18.4	75

Since these links are power starved the lowest inner code (R½) is used for both DVB-S and DVB-S2. The resulting gain is 2.4 dB for S2 over S. The DVB-S2 standard includes lower code rates but the JIPM DVB-S2 only goes to R½ . Since both links are designed for the same loss the availability maps are identical.

Findings & Caveats

1. Link Performance: Using BOL EIRPs with disadvantaged beams, both Modems provide large capacities with respectable availabilities. DVB-S2 outperforms DVB-S due to better power and bandwidth efficiencies. The wide WGS channels allow extensive power/bandwidth tradeoffs.

2. BOL EIRP: The WGS1 BOL EIRPs are about 3 dB higher than specification. Results for WGS2 & WGS3 are not currently known. Even if WGS2 & WGS3 have similar BOL values, these can degrade over the course of the WGS life resulting in poorer performance than indicated here.

3. Modem Performance: DVB-S performance is based on the SDM-2020 modulator at the Teleports and DVB-S2 is based on JIPM measurements. Lower code rates for DVB-S2/JIPM would improve the WGS/DVB-S2 performance for both spot and area beams.

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