The Rucksack Portable Receive Suite Performance over WGS using the DVB-S2 Mini IRD

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The Rucksack Portable Receive Suite (RPRS) is a light weight (less than 20 lbs.) GBS RS using a Ka-band phased array (approximately 193 square inches). The RPRS is capable of operation with a Mini Integrated Receiver Decoder (MIRD). The MIRD uses a limited version of the DVB-S2 standard (QPSK only with symbol rates from 1Msps to 23Msps in 1Msps increments). The MIRD is receive-only with a single tuner and is certified for TRANSEC operation.

The Next Generation Receive Terminal (NGRT) is an operational, GBS receive-only terminal capable of operation with DVB-S2 using the Joint IP Modem (JIPM) version1 IRD when it is available. The NGRT uses a parabolic reflector antenna nearly 1m in diameter. The JIPM has a full complement of DVB-S2 modulations and code rates (symbol rates from 1Msps to 50Msps in 1Msps increments) as well as TRANSEC. The MIRD and the future JIPM IRD remote Modem will be fully integrated with JIPM Network Control Centers at the various DoD Teleports. This will allow the JIPM NCC to support the RPRS/MIRD and the NGRT/JIPM-IRD on the same DVB-S2 broadcast using Variable Coding and Modulation (VCM).

This paper will determine the capacity of the RPRS/MIRD network, the NGRT/JIPM network and the combined network using a VCM broadcast over WGS at Ka-band. The approach will use a fixed symbol rate (23Msps maximum) for the individual broadcast streams and will maximize the combined network capacity. The modulation and coding will be chosen to maximize the network combined capacity consistent with both terminals having a similar propagation margin.

I. INTRODUCTION

The current GBS program provides broadcast services over WGS spot beams using 45Mbps, DVB-S carriers to land-based NGRT (1m) terminals [1]. GBS is scheduled to be transitioned into the JIPM forward using DVB-S2 in 2013. This paper explores the introduction of the RPRS terminals (17.03” x 11.33”) into the GBS broadcast using a variant of the JIPM forward with a limited set of ModCodes and symbol rates [2]. This paper explores the use of VCM to support both terminal types in the same broadcast.

Paper Convention

This paper will use the following conventions:

Symbol	***Definition***	***Units***
Rs	Symbol rate	Msps
Rb, burst rate	Burst rate=Rs*bits/sym	Mbps
R	User rate	Kbps
Throughput Eff	ModCode & Encap Eff	R/Rb
PER	Packet Error Rate	unitless
EIRP	Effective radiated power	dBW
Eb/No	Energy/bit	dB
L	Propagation loss	dB
MIRD	Mini IRD	
BOL	Beginning of Life	
NGRT	Next Generation RT	
RPRS	Rucksack Portable RS	
JIPM	Joint IP Modem	
ModCode	Modulation & Code rate	
Bits/symbol	Alphabet size*FEC rate	
DVB-S2	JIPM Forward Link	

II. LINK DEFINITION

Terminals

The terminal parameters are defined in [1, 2].The table below summarizes the terminal parameters at 21 GHz.

	Noise Figure	Antenna Gain	G/T at L=3.5dB	Pointing Error Loss
NGRT	1.4dB	43.56dBi	18.60dB/k	0.5dB
RPRS	1.4dB	36.33dBi	11.36dB/k	0.1dB

The terminal G/Ts are shown to differ by 7.2dB.

WGS

It is assumed that the Narrow Coverage Antenna 5 (NCA5) spot (1.5 degree) beam covers the intended terminal users at the Edge of Coverage (EOC). NCA5 has two-125MHz channels. It is assumed that the power is split evenly between each channel. In keeping with current practice it is assumed that 2-GBS carriers share one channel. Each channel has 48distinct-2.6MHz sub-channels for a total of 124.8MHz of available bandwidth. Within that channel each carrier can occupy as much as 62.4MHz. Assuming a 30% filter roll-off, this will support a symbol rate as high as 48Msps.

The following table summarizes the NCA5 downlink nominal power per GBS carrier.

	EIRP (dBW)	Power share(dB)	Power Rob(dB)	EIRP/Carr (dBW)
BOL	57.3	6	0.2	51.1
EOL	55	6	0.2	48.8

It is assumed that NCA1 is placed on a Teleport which has a KaStars V1 (9.1m) terminal. The V1 terminal shares both GBS and non-GBS traffic [1].

DVB-S2 CCM and VCM

The JIPM forward physical layer is shown in Figure 1.

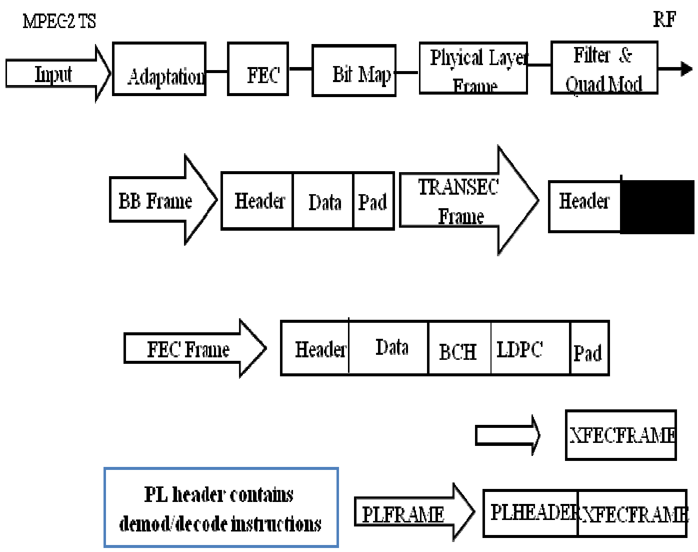

Figure1 JIPM DVB-S2 Physical Layer Framing

The JIPM forward differs from the DVB-S2 physical layer by the addition of the TRANSEC framing [3, 4].

The current GBS system uses DVB-S which is not capable of VCM. The JIPM can support CCM as well as VCM [3, 4]. The difference between CCM and VCM is illustrated in Figure 2.

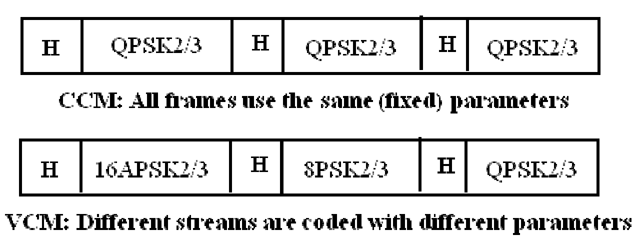

Figure 2 CCM and VCM Illustration

VCM can provide individual streams to the NGRT and the RPRS from the same broadcast simultaneously because the synchronization and the headers are heavily protected. This allows the RPRS to "read" the headers and determine which stream is intended for it.

III MODEM Power and Throughput Capabilities.

The companion paper [9] develops the power and throughput efficiency in detail. Those results are summarized in this section.

Required Eb/No

The following table shows the required Modem Eb/No requirements (second and third column) based on back/back Es/No specifications but converted to end-to-end Eb/No values as described below.

	JIPM IRD	Mini IRD	JIPM IRD	Mini IRD
ModCode	Eb/No	Eb/No	Eff	Eff
QPSK1/4	--	2.46	--	0.923
QPSK1/3	--	2.26	--	0.925
QSPK2/5	--	2.40	--	0.926
QPSK1/2	2.60	2.60	0.950	0.950
QPSK3/5	3.13	3.13	0.950	0.950
QPSK2/3	3.22	3.22	0.951	0.951
QSPK3/4	3.67	3.67	0.951	0.951
QPSK4/5	4.02	4.02	0.951	0.951
QPSK5/6	4.34	4.34	0.951	0.951
QPSK8/9	5.08	5.08	0.951	0.951
QPSK9/10	5.23	5.23	0.951	0.951
8PSK 3/5	5.14	--	0.927	--
8PSK 2/3	5.70	--	0.928	--
8PSK 3/4	6.38	--	0.928	--
8PSK 5/6	7.33	--	0.928	--
8PSK 8/9	8.40	--	0.950	--
8PSK 9/10	8.65	--	0.950	--
16APSK2/3	7.60	--	0.925	--
16APSK 3/4	8.34	--	0.926	--
16APSK 4/5	8.86	--	0.926	--
16APSK 5/6	9.24	--	0.926	--
16APSK 8/9	10.24	--	0.926	--
16APSK 9/10	10.45	--	0.926	--

Table1 Modem Eb/No and Throughput Efficiency

The Modems are specified in terms of Es/No at a PER of 10e-6 [4, 6]. At the time of the writing of this paper, the MIRD back/back tests have not been completed. The table assumes an end/end (channel) degradation of 0.6dB, 0.9dB and 1.3dB for QPSK, 8PSK and 16APSK respectively. The specification for both ViaSat Inc Modems is identical in terms of Es/No in the overlapping regions of the ModCodes [4, 6]. The Eb/No is computed from the Es/No by scaling for the ModCode spectral density. The extrapolation of the PER from 10e-6 to 10e-7 is obtained by adding 0.1dB to the 10e-6 results (justified by the simulation in the DVB-S2 standard [3]).

Throughput

The throughput efficiency is defined in this paper as the physical layer, baseband layer as well as IP encapsulation efficiencies illustrated in Figure1.

Several factors determine the throughput efficiency. The encapsulation efficiency includes: IP over MPEG encapsulation (not shown in Figure1), the mode adaptation, the stream adaptation which may require padding and the physical layer framing efficiency. All of the encapsulations shown in Figure 1 contribute to the throughput efficiency. Some of the ModCodes require pilots to assist the carrier tracking loop [3] which also adds to the transmission overhead.

The IP over MPEG encapsulation is performed by the multi-protocol encapsulation (MPE) which allows concatenation of IP packets [8] into MPEG2 sections. This mechanism for transporting data on top of the MPEG2 transport streams is prior to the front end shown in Figure 1. The IP over MPEG efficiency depends on the packet size and hence the user traffic. The JIPM specification [7] requires the DVB-S2 Modem to utilize at least 95% of available capacity for user IP packets where the IP packet size is 1300 bytes. During the JQT tests IP packets filled more than 99% of available capacity: that efficiency factor was used in table 2. More generally the MPE efficiency depends on the actual traffic load and can result in much lower efficiencies.

IV. LINK ANALYSIS

Using the link parameters of section I and the power and throughput efficiencies of section II, the supportable data rates will be determined for the two terminal-Modem pairs for the assumed propagation loss of 3.5dB. The two VCM carriers in the target NCA5 channel must operate with the constraint that the maximum symbol rate is 23Msps. Finally, an FDM case will be considered where there two independent CCM carriers each targeted for one of the two terminal types.

Assumptions

The following assumptions are made:

- JIPM is upgraded to support FEC rates 1/4,1/3, 2/5
- Support the two terminal types via 2 identical VCM carriers or two different CCM carriers
- VCM dwell time is split 50/50 for each ModCode. VCM overhead is 1%.
- VCM transmissions run at the same symbol rate which is less than or equal to 23Msps

Reference Link Budgets

The reference link budgets are shown in table2.

RPRS Vs NGRT for NCA5	NGRT-JIPM	RPRS-MIRD	NGRT-JIPM	RPRS-MIRD	
	NCA5 BOL	NCA5 BOL	NCA5 EOL	NCA5 EOL	
# of down-link channels	2	2	2	2	
terminal EIRP up (dBW)	85	85	85	85	Linear
power sharing factor	12.43	12.25	12.43	12.15	Uplink Sharing
carrier EIRP up (dBW)	72.57	72.75	72.57	72.85	
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	96.57	96.75	96.57	96.85	
beam EIRP	56.84	57.51	54.6	54.97	Operating EIRP
power sharing factor (dB)	6.0	6.0	6.0	6.0	Multi-Chan, 2-Carr
power robbing (dB)	0.13	0.18	0.18	0.18	up noise,Ims
carrier EIRP down	50.7	51.3	48.4	48.8	GBS Carrier
prop loss	3.5	3.5	3.5	3.5	Supportable Loss
other losses	0.6	0.1	0.6	0.1	Fixed
free space loss	210.36	210.36	210.36	210.36	Mosul, f=21
terminal G/T	19.07	11.26	19.07	11.26	Deg G/T
down C/No	83.9	77.2	81.6	74.7	
C/No for IM	96.56	94.83	96.91	94.51	23
C/No for other	500	500	500	500	
net C/No	83.5	77.1	81.4	74.6	
burst info rate	51.50	25.1	41.30	16.68	Rb (Mbps)
available Eb/No	6.3	3.1	5.2	2.4	
required Eb/No	6.38	3.13	5.23	2.4	
margin	0.0	0.0	0.0	0.0	
net transport rate	47.79	23.83	39.28	15.44	R (Mbps)
mod code #	8PSK 3/4	QPSK 3/5	QPSK 9/10	QPSK 2/5	
inner code	3/4	3/5	9/10	2/5	
overall code rate	1.1206	0.60	0.8980	0.3970	
Rs	23.00	21.00	23.00	21.00	
BW	29.90	27.30	29.90	27.30	

Table2 Reference Link Budgets

The link budgets are shown for 21Msps for the RPRS and 23Msps for the NGRT.

Optimum Rates for NCA5 BOL with Rs</=23Msps

The power/symbol rate balance is shown in table3 for the CCM, RPRS-BOL case.

	Rs	Bps/Hz	Burst rate	User rate
QPSK1/4	23	0.49	11.36	10.49
QPSK1/3	23	0.66	15.2	14.06
QPSK2/5	23	0.79	18.26	16.91
QPSK1/2	23	0.99	22.86	21.72
QPSK3/5	21	1.19	25.08	23.83
QPSK2/3	19	1.33	25.24	24.0
QPSK3/4	15	1.49	22.41	21.31

Table3 User Rate Vs ModCode for RPRS-BOL

The optimum occurs for QPSK 2/3 with an Rs of 19Msps although the 21Msps case is nearly the same.

The power/symbol rate balance is shown in table 4 for the CCM, NGRT-BOL case

	Rs	Bps/Hz	Burst rate	User rate
QPSK5/6	23	1.66	38.22	36.35
QPSK8/9	23	1.77	40.80	38.80
QPSK9/10	23	1.80	41.31	39.29
8PSK3/5	23	1.79	41.20	38.19
8PSK2/3	23	1.99	45.83	42.53
8PSK3/4	23	2.24	51.55	47.84
8PSK5/6	18	2.49	44.87	41.64

Table 4 User Rate Vs ModCode for NGRT-BOL

The optimum in this case occurs for 8PSK3/4 with an Rs of 23Msps.

V. NGRT & RPRS VCM

Using the symbol-rate-constrained CCM mode, Figure2 shows the user rates versus ModCode

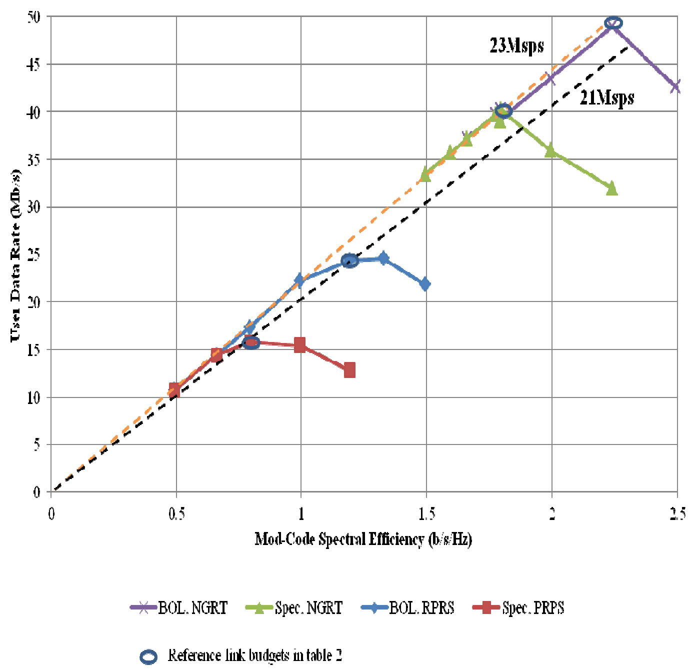

Figure 2 User Rate versus ModCode Spectral Density

The figure shows the results for the BOL and Spec values for NCA5. Also shown on the figure are the slopes representing symbol rates of 23Msps and 21Msps.Note that only points on or above the line can be supported for the selected symbol rate. The approach is to select a symbol rate that provides a good composite rate for both Modem-terminal pairs.

VCM Link Budgets

The following table compares the CCM and the VCM NGRT link budgets for symbol rates of 23Msps and 21Msps

CCM/VCM/23,21	NGRT-CCM	NGRT-VCM	NGRT-CCM	NGRT-VCM	
NCA5/BOL	23Msps	23Msps	21Msps	21Msps	
# of down-link channels	2	2	2	2	
terminal EIRP up (dBW)	85	85	85	85	Linear
power sharing factor	12.43	13.34	12.43	13.63	Uplink Sharing
carrier EIRP up (dBW)	72.57	71.66	72.57	71.37	
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	96.57	95.66	96.57	95.37	
beam EIRP	56.84	56.89	56.37	56.37	Operating EIRP
power sharing factor (dB)	6.0	6.0	6.0	6.0	Multi-Chan, 2-Carr
power robbing (dB)	0.13	0.13	0.13	0.13	up noise,Ims
carrier EIRP down	50.7	50.7	50.2	50.2	GBS Carrier
prop loss	3.5	3.5	3.5	3.5	Supportable Loss
other losses	0.6	0.6	0.6	0.6	Fixed
free space loss	210.36	210.36	210.36	210.36	Mosul, f=21
terminal G/T	19.07	19.07	19.07	19.07	Deg G/T
down C/No	83.9	83.9	83.5	83.5	
C/No for IM	96.56	96.41	96.91	97.86	
C/No for other	500	500	500	500	
net C/No	83.5	83.4	83.1	83.0	
burst info rate	51.55	51.55	47.06	47.06	Rb (Mbps)
available Eb/No	6.3	6.3	6.3	6.3	
required Eb/No	6.38	6.38	6.38	6.38	
margin	0.0	-0.1	0.0	-0.1	
user rate per link	47.83	34.50	44.76	21.60	R (Mbps)
mod code #	8PSK 3/4	8PSK 3/4	8PSK 3/4	8PSK 3/4	
inner code	3/4	3/4	3/4	3/4	
overall code rate	1.1206	1.1206	1.1206	1.1206	
Rs	23.00	23.00	21.00	21.00	
BW	29.90	29.90	27.30	27.30	

Table 5 NGRT CCM & VCM at 23Msps and 21 Msps

The burst rates are 51.55Mbps and 47.06Mbps for symbol rates of 23Msps and 21Msps respectively based on the spectral efficiency of 8PSK3/4. The difference in the beam EIRP reflects the different TWTA output back-offs. The user rates are based on a 50% dwell on each ModCode stream (in the TDM stream) and a 1% overhead for the ModCode TDM process (the resulting VCM efficiency is 49.5%). The user rates reflect this overhead.

VCM using 23Msps and NCA5 BOL

The following table shows VCM terminal user rates using the throughput efficiencies (table 1) and the VCM efficiencies

	ModCode	Rb	Overall Eff	VCM rate
NGRT	8PSK3/4	51.5	0.459	23.7
RPRS	QPSK1/2	22.9	0.470	10.8

Table 6 Terminal VCM User Rates for 23Msps

The overall efficiency is a product of the encapsulation and framing efficiency shown and the VCM efficiency (0.495). The overall network rate is 34.5Mbps for each carrier or a total of 69Mbps for the two carriers.

VCM using 21Msps and NCA5 BOL

The following table is the same as table 5 for a 21Msps symbol rate.

	ModCode	Rb	Overall Eff	VCM rate
NGRT	8PSK3/4	47.1	0.459	21.6
RPRS	QPSK3/5	25.1	0.470	11.8

Table 7 Terminal VCM User Rates for 21Msps

The overall network rate is 33.4Mbps which is less than the 34.5Mbps VCM rate for the 23Msps case (table 6). However, the RPRS VCM rate is higher for the 21Msps case than the 23Msps case. This could be important depending on the operational scenario.

VI. NGRT & RPRS FDM Carriers

Using two independent CCM carriers in the considered channel (referred to as the FDM case in this paper) is shown in table 8.

FDMA 2-CCM Carriers	NGRT-JIPM	RPRS-MIRD	
	NCA5 BOL	NCA5 BOL	
# of down-link channels	1	1	
terminal EIRP up (dBW)	85	85	Linear
power sharing factor	10.74	16.81	Uplink Sharing
carrier EIRP up (dBW)	74.26	68.19	
prop loss	3.3	3.3	Clear Sky
other losses	0.9	0.9	Fixed Losses
free space loss	214.2	214.2	14 deg, 30.5GHz
satellite G/T	13.8	13.8	Off Peak
up C/No	98.26	92.19	
beam EIRP	57.45	57.45	PR=0.18dB,OBO=3.34
channel sharing factor (dB)	3.0	3.0	Two-Chan
Oper EIRP/Channel(dB)	54.5	54.5	
carrier EIRP down	50.9	51.8	Selected power mix
prop loss	3.5	3.5	Targetted Loss
other losses	0.6	0.1	Pointing error
free space loss	210.36	210.36	Mosul, f=21
terminal G/T	19.07	11.26	Deg G/T
down C/No	84.1	77.7	
C/No for IM	94.03	94.94	
C/No for other	500	500	
net C/No	83.5	77.5	
burst info rate	62.01	27.46	Rb (Mbps)
available Eb/No	5.6	3.1	
required Eb/No	5.7	3.13	
margin	-0.1	0.0	
net transport rate	57.54	26.09	R (Mbps)
mod code #	8PSK 2/3	QPSK 3/5	
inner code	2/3	3/5	
overall code rate	0.6642	0.60	
Rs	31.12	23.00	
BW	40.46	29.90	
Propagation loss per beam	3.5	3.5	

Table8 FDM Reference Links

. For the design point, the NGRT carrier is allocated a symbol rate of 31.12Msps and the RPRS carrier is allocated 0.9dB more downlink power than the NGRT carrier. The WGS beam TWTAs must be backed off at least 3.3dB which favors the FDM approach. The TWTW operating point is 3.34dB output back-off which is near the ARSTRAT-imposed limit. The supportable rates (with the 3.5dB propagation loss constraint) are 57.54Mbps and 26.09Mbps for the NGRT and RPRS terminals respectively. The NGRT-carrier is constrained by the JIPM maximum symbol rate of 50Msps while the RPRS carrier is constrained by the maximum 23Msps rate of the MIRD.

VII.VCM and FDM Comparison

The VCM approach uses two-identical carriers with TDM streams intended for the individual terminals from the same Gateway location. The FDM approach uses two independent CCM carriers intended for the individual terminals.

The following table compares the total user data rates (from both carriers) for the VCM and the CCM cases.

	2-VCM Rates	2-CCM Rate
NGRT	47.4	57.5
RPRS	21.6	26.1
Net Rate	69	83.6

Table 9 VCM & FDM Comparison

The FDM approach results in greater capacity to both terminals. This is a consequence of the fact that the WGS satellite operates in a quasi-linear mode with the beam TWTAs backed-off at least 3.3dB. For operation over the GBS UFO satellites this would not be the case as the beam TWTAs in this case operate very close to saturation.

Using the FDM approach, the uplinks do not have to be co-located. This flexibility could be important in an operational scenario where the feed intended for either terminal is already in theater (e.g., a Theater Injection Point [TIP] could provide an in-theater feed intended for the RPRS over the WGS satellite). On the other hand, the VCM approach is more network centric allowing a more judicious choice of traffic on the individual terminal feeds.

Conclusions

Under the current MIRD symbol rate limit of 23Msps, it can be better to use two separate carriers to support the NGRT and the RPRS over WGS. For the reference links, the Independent FDM carriers result in a 21% increase in user rates for both terminals. The reasons for this are:

- WGS is quasi-linear favoring FDM over TDM
- With VCM, each TDM carrier gets equal power and bandwidth
- With FDM, each carrier is different

- NGRT gets more bandwidth
- RPRS gets more power

Note, however, that the case for FDM over VCM is true under the assumptions that both terminals need maximum capacity, and that there is minimal duplication of traffic delivered over the two carriers. The 21% capacity advantage may be partially or fully mitigated by network-level considerations outside the scope of this paper: time-varying data requirements, duplication of traffic, use of flow-control to opportunistically fill the DVB-S2 forward link among others.

Further the VCM approach requires both TDM feeds to be co-located at the JIPM Modulator location. Using the Independent FDM approach, the feeds don't have to be co-located. One feed could be in theater and the other at a gateway. In certain cases this could be operationally significant. Since the JIPM remote Modem has dual DVB-S2 receivers, the NGRT could receive its traffic and all traffic intended for the RPRS. In contrast, the MIRD remote Modem has a single tuner, receiving only traffic for the RPRS.

A note of caution is in order. Typical broadcast satellites run their TWTAs close to saturation. This includes the GBS payload on UFO8 and UFO10. Under these conditions, the balance could favor VCM.

Recommendations

It is recommended that efforts be made to increase the MIRD symbol rate to perhaps 30-35 Msps. This depends on the tradeoff between the symbol rate and impacts on the thermal and power requirements in the RPRS.

It is recommended that the upcoming JIPM/WGS3 tests consider the link cases defined in this paper. This paper used specification values for the Modem back/back performance. Extensions were then made to end/end performance in terms of Eb/No making assumptions about RF performance. These tests provide two opportunities:

- Validate the results presented here
- Determine end/end measured Modem performance

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