Bandwidth and Power comparison for C/Ku Band Satellite Networks

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***Abstract*—Optimization of bandwidth and power according to bit error rate and energy per bit requirement is a basic requirement for any service provider and customer. Quality of service (QoS) is more influenced over a satellite network due to its specific characteristics like long propagation delay, lossy links etc. Two satellite video broadcasting standards, Digital Video Broadcasting-Satellite (DVB-S) and Digital Video Broadcasting-Satellite-second generation (DVB-S2) are being utilized for this research work for both C & Ku Band real time configuration. Comparison for bandwidth and power is carried out using different modulation types, data rates, forward error correction and code rates. Optimization of bandwidth and required power is analyzed with extensive calculations and link budgets of the satellite link.**

***Index Terms*— DVB-S/S2, Bandwidth, Power, EIRP, E_b/N_o.**

I. INTRODUCTION

SATELLITE networks can be used for multimedia applications like voice and video streaming due to global coverage. Especially satellite internet protocol (IP) networks can also support multicast and point to point broadcast services. Some of the services include high speed internet, data services, video and data streaming, interactive video and Television broadcast. Satellite communication has become the powerful communication source for remote areas where whether the wired connection is impossible or it is very costly [1]. Some of the latest applications of satellite communication using small terminals are telemedicine and tele-education.

In video streaming through internet protocols, dealing with quality of service is very important and is affected by many parameters in general like; propagation delay from sender to receiver due to satellite link, energy per bit for the signal received at far end and finally bit error rate which is inversely proportional to energy per bit. The quality of service in video streaming over satellite networks depicts that how precisely video contents are received at far end without any interruption and degradation [2]. Time to establish connection for the first time, reconnection rate, peak signal to noise ratio of video and synchronization between audio and video also play important role in video quality of service.

When the system for analyzing video streaming related parameters is made more flexible, it also enhances the complexity of the whole system and makes careful optimization of different parameters. The overall performance evaluation is dependent on multiple inter related problems, such as the distortion-rate performance and error resilience of the video and audio codec source, the error correction capability of the channel codec in satellite modem and the characteristics of the channel. Due to this reason; interaction of the system components and the influence of individual parameters is difficult to understand. The design of the overall system might become a dreadful task [3].

The rest of the paper is divided into following sections: Section-II describes the DVB-S/S2 and DVB-RCS standards; Section-III is about the satellite infrastructure used to perform the measurements; Section-IV presents the analysis & results and Section-V concludes the paper.

II. DVB-S/S2 AND DVB-RCS

Two protocol standards are normally used in broadcasting over satellite networks, the DVB-S and DVB-RCS [4]. Digital Video Broadcasting via Satellite is being used in forward channel and Digital Video Broadcast- Return Channel via Satellite standard for return channel. DVB-RCS standard was originally visualized with either the Asynchronous Transfer Mode or an IP-based network interface.

Second generation video broadcasting standard (DVB-S2) was approved in 2004. As per comparison described by Comtech EF Data in migration from DVB-S to DVB-S2 and related spectral efficiencies in 2009, made with initial standard DVB-S, the second generation standard (DVB-S2) provides fundamental changes for both physical and access layers ensuring bandwidth improvement, which is efficiently increased over all existing systems. The digital video broadcasting protocols were basically designed to support digital television transmission, including both video and audio. These protocols are being supported by MPEG-2 Transport Stream (TS) that multiplexes the different streams. After that, encapsulation protocols in addition supported for Internet Protocol services [5].

DVB standards are being developed keeping market driven approach. Through this principle the second generation standard specifications provided improved capacity and robustness as well as support for new business architecture. As a result, the 2nd generation standards are very successful as compared to their predecessors. With the second generation, the DVB project has expanded its capability to deliver new and successful standards addressing the relevant market needs of the date [6].

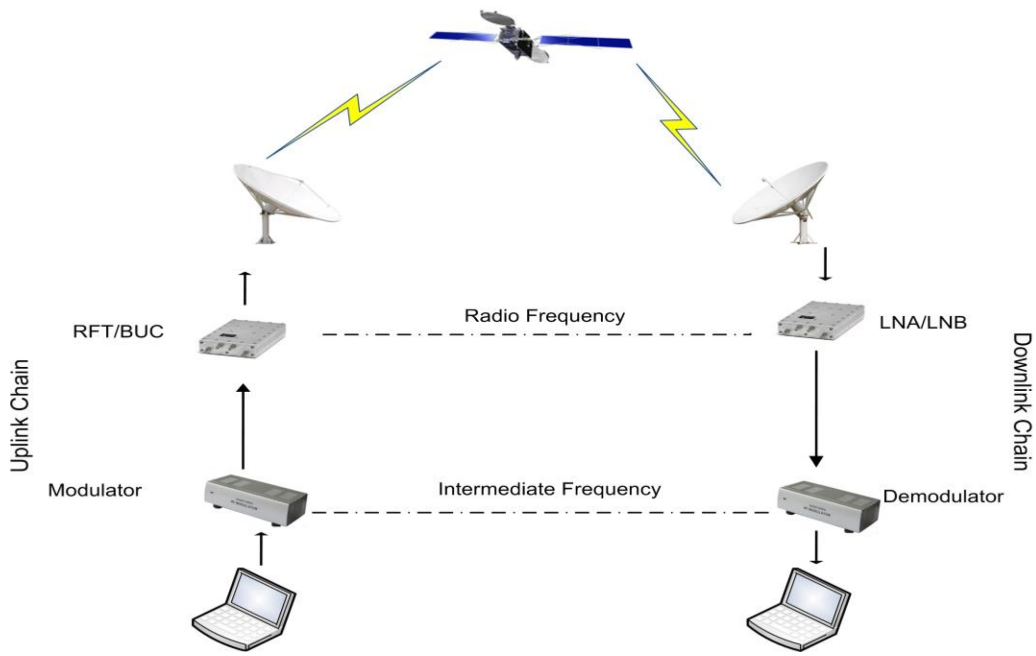


Fig. 1: Satellite network

III. METHODOLOGY

Satellite ground station infrastructure at base band level and RF level is implemented to produce real time results in accordance with link budget calculations so that both can be verified. Ground station infrastructure consists of two types of configurations, one configuration of C-band and other for Ku-band.

Very small aperture terminal (VSAT) is installed for the establishment of DVB-RCS link. There are two satellite dish antennas with diameters of 1.8 and 3.8 m. One of them is for C-Band and other is for Ku-Band for duplex communication via satellite.

In downlink chain, two types of configurations are used. In first configuration, low noise amplifier (LNA) is used after antenna feed and orthomode transducer (OMT), operating in radio frequency range. OMT can transmit and receive signal in different polarizations e.g., transmit in horizontal and receive in vertical polarization. A radio frequency transceiver (RFT) of 50 W is used which has gain of 74 dB in uplink and 45 dB in downlink. RFT converts the signal from radio frequency (RF) to intermediate frequency (IF), which then is sent via coaxial cable to the satellite modem. The satellite modem adds a loss of 2dB in each of the uplink and downlink chain. Two types of modems are used; one is IF L-Band which receives a signal in 750-2050 MHz (used for Ku-Band) and other is IF signal of 70-140 MHz (used for C-Band). The local oscillator converts the signal to baseband frequency. After demodulation, the signal is received at Polycom camera codec through CISCO router, which decodes the signal and displays it on monitor. In the uplink chain, the signal takes the reverse path to reach the satellite modem. The satellite modem can modulate the signal at different code rates, modulation types and data rates at desired uplink IF frequency. The signal is sent to RFT for up conversion to C-Band and after amplification it is send to antenna feed for transmission to the satellite.

In 2nd configuration, low noise block down convertor (LNB) is used instead of LNA in downlink chain. LNB converts Ku-Band to L-Band with a gain of 60 dB. Similarly in the uplink chain, the signal from modem is received by 25 W block up-convertor (BUC) which converts IF L-Band signal to Ku-Band and amplifies the same signal to orthomode transducer (OMT) with a gain of 68 dB and then sends it to antenna feed for transmission.

For video encoding and decoding, Polycom High Definition series (HDX) Camera and codec systems are used which support H.323 over both Internet Protocol version 4 & Internet Protocol version 6. Satellite modem can support both IPv4 and IPv6 under differential services [7].

The satellite configuration is shown in Table 1.

Table 1: Satellite configuration

Parameter	Value
C Band Modem IF Frequency	70 MHz
Ku-Band modem IF frequency	1000 MHz
Polycom data rate	1024 Mbps
25 W BUC attenuation	6 dB
50 W RFT attenuation	3 dB
C-Band modem power level	-20 dBm
Ku-Band modem power level	-30 dBm
BUC LO frequency	12800 MHz
LNB LO frequency	10000 MHz

IV. LINK BUDGET ANALYSIS

To achieve minimum performance standards, communication channels are designed with the limitation of channel bandwidth and transmitter power. Most critical performance parameter is bit energy per noise density ratio which can be calculated as

$$E_b/N_o = (C/N)(B/r_b)$$

where 'B' is required bandwidth, 'C/N' is carrier to noise ratio and 'r_b' is data bit rate which can be given by

$$r_b = B\log_2 M/(1+\alpha)$$

where 'M' is number of symbols for each phase of modulation scheme. 'α' is channel filter roll of factor. Ideally its value is zero but practically for DVB-S its 35-40% while for DVB-S2, it is 20-25%.
Carrier to noise ratio can be calculated as

$$C/N = EIRP_s - FSL_{downlink} - (G/T)_s - B_s k - L_s$$

where '$EIRP_s$' is the effective isotropic radiated power by satellite, 'G/T' is figure of merit of satellite, 'B_s' is satellite transponder bandwidth, 'k' is Boltzmann constant having value of 1.38×10^{-23} J/K and 'L_s' is combination of different transmission losses. Free space loss (FSL) is power loss produced due to the spreading of the signal in space and can be calculated by

$$FSL = 4\,\pi\, d / \lambda^2$$

where 'd' is distance of satellite from earth station and 'λ' is wavelength which is ratio of speed of light (c) to frequency of transmission.
Received power at ground station is given by

$$P_{Received} = EIRP_s + G_{system} - AA - FSL_{downlink} - RFL - AML - PL - T_{system}$$

where 'AA' is the atmospheric absorption loss due to rain and gases, 'RFL' is receiver feeder loss and it occurs between the receive antenna and the receiver due to connectivity of waveguides filters and couplers. 'AML' is the antenna misalignment loss includes both pointing and polarization loss, resulting from antenna misalignment and 'PL' is depolarization loss due to ionosphere. 'T_{system}' is system temperature which can be calculated by

$$T_{system} = T_{ANT} + T_{LNA} + T_{CL} + T_{rain}$$

where 'T_{LNA}' is noise temperature of low noise amplifier (LNA), 'T_{rain}' is temperature due to rain attenuation while 'T_{CL}' is clear sky noise temperature. 'L' is power loss by absorption network.
System gain can be calculated as

$$G_{system} = G_{LNA} + G_R$$

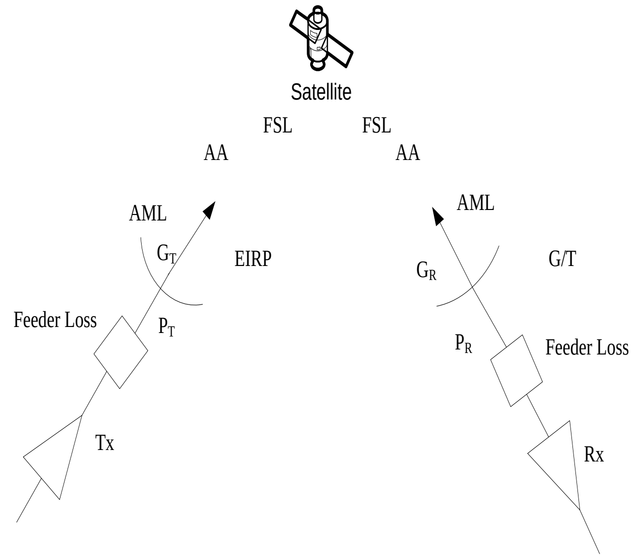


Fig. 2: Transmit/Receive chain gain/loss

where 'G_R' is gain of receive antenna and 'G_{LNA}' is gain of LNA.
Antenna receive gain (G_R) and transmit gain (G_T) at injection point is calculated by

$$G = 10\log\,(A_{eff} \times 4\,\pi / \lambda^2)$$

Effective antenna area can be given as

$$A_{eff} = R^2\,\pi\,\eta$$

where 'R' is radius of antenna. Efficiency of antenna 'η' can be calculated as

$$\eta = G\,(c / 2\,\pi\, R\, f)^2$$

EIRP transmitted from earth station is

$$EIRP_{ES} = P_T + G_T - AML - \text{Feeder loss}$$

V. RESULTS

Real time satellite network measurements and extensive budgeting results will demonstrate the comparison of bandwidth and power.
Satmaster [8] is designed as a general tool for use within the satellite industry. Signal propagation, antenna aiming (including dual feeds), link budget analysis and solar outage prediction provide the backbone to the package. The link budget modules employ industry standard rain attenuation and atmospheric modeling. Satmaster is a multi-document interface (MDI) program. Some calculations are done using this software such as bandwidth, equivalent power values for both C and Ku band. Radio Frequency Transceiver (RFT) and block up convertor (BUC) size is also estimated from this software.
In our analysis, different modulation schemes [9] like Binary Phase Shift Keying (BPSK) which is the modulation technique where

Table 2: Parameters

Modulation	BPSK	QPSK	8-PSK	16-QAM	16APSK
TPC	0.3125 0.48 0.75 0.875	0.48 0.5 0.75 0.95	0.75 0.875	0.75	0.75
Modulation Index	1	2	3	4	
Roll of Factor (α)	1.35/1.2				

two different phase values are indicated with two different data symbols, Quadrature Phase Shift Keying (QPSK), Eight Phase Shift Keying (8-PSK), 16-Ary Amplitude and Phase Shift Keying (16APSK) and 16-state Quadrature Amplitude Modulation (16-QAM) are used to produce real time results. Turbo Product Coding (TPC) is used with different code rates as indicated in Table 2 with all modulation schemes. Modulation Index and roll of factor shown in Table 2 are used to calculate the bandwidth of the carrier using following formula:

$$\text{Bandwidth (B)} = \text{Data rate} \times \alpha /(\text{FEC x MI})$$

A. BW Utilization

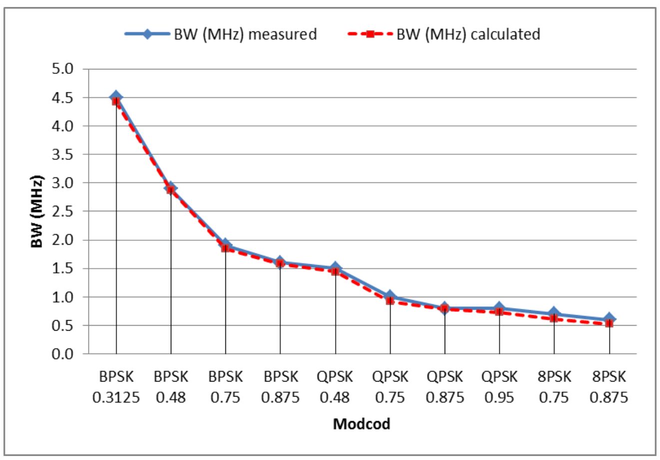
There are different ways of defining bandwidth (BW); two of them are 3 dB bandwidth and 10dB BW. Defining the 3 dB BW, it is the distance from one pass-band edge to the other where amplitude is 3 dB below the maximum point.

Figure 3(a) shows bandwidth utilization in DVB-S, where calculated results are computed by formulae and Satmaster pro software with real time measured results. The difference between two results is due to additional bits being sent by satellite modem with original data for different modulations and FEC code rates. Similar is the case for Figure 3 (b); here the results are shown for DVB-S2 in comparison with DVB-S. For the systems which are bandwidth limited, higher order modulations can be used because plenty of power is required for them. If the system is power limited then only lower order modulations of DVB-S can be used.

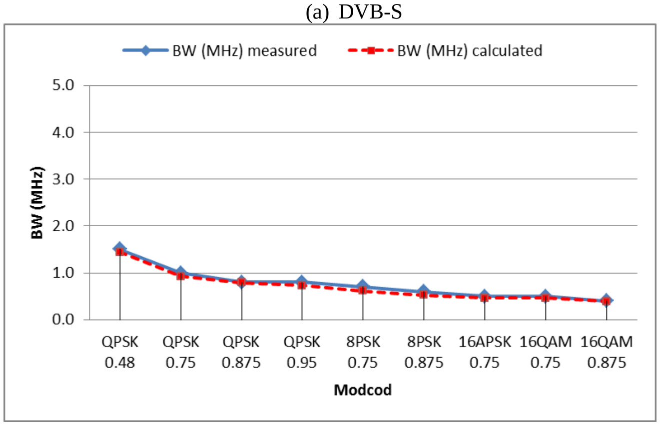
B. Power Utilization

Normally during link analysis transponder usage is taken as bandwidth limited because most of the satellite operators have concern about bandwidth limitation to ensure minimum permissible input power to transponder's travelling wave tube amplifiers (TWTA). Power limitations are allowed to special customers using automatic level control (ALC) whether at satellite TWTA or ground station TWTA.

Power analysis for different modulations and forward error correction (FEC) codes is depicted below. Figure 4 shows power utilization in C-band. As we move from lower to higher modulation and FEC code rate, required power increases. As FEC code rate varies the number of redundant / correction bits varies, for ¾ the redundant bits are 25% of the payload and similarly for 0.95, only 5% are correction bits, so more power is required for this code rate to ensure all bits reach the

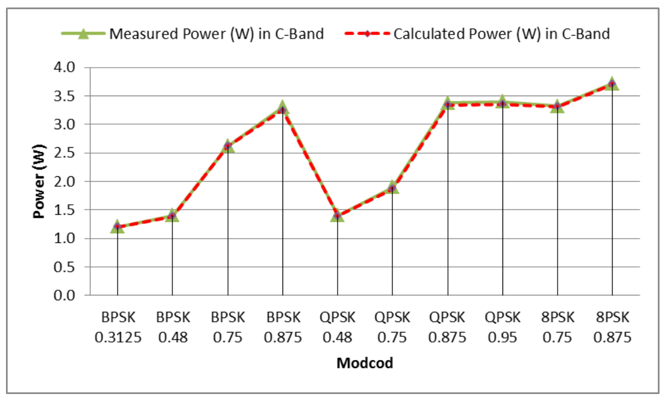


(a) DVB-S



(b) DVB-S2

Fig. 3. Bandwidth utilization



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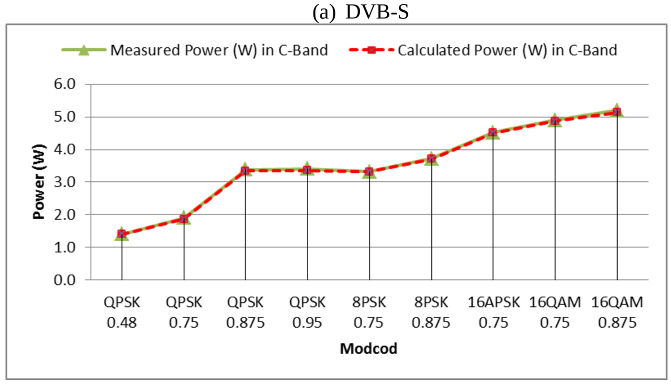
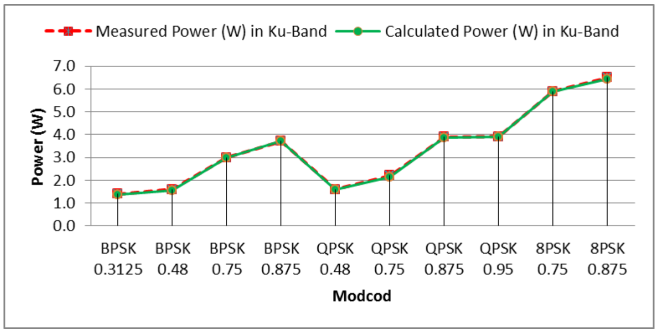
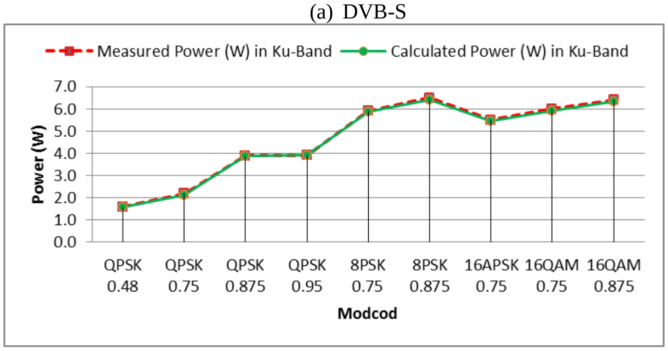


(b) DVB-S2

Fig. 4. C-band power utilization



(a) DVB-S



(b) DVB-S2

Fig. 5. Ku-band power utilization

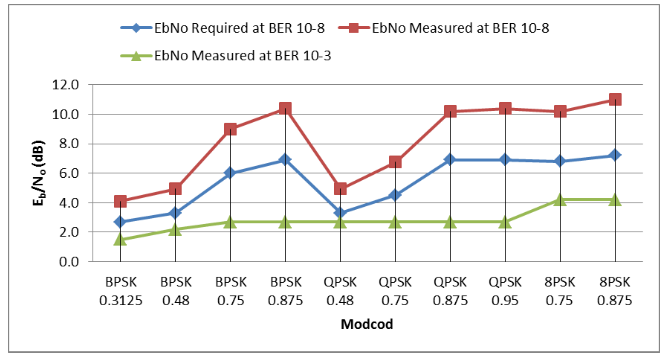
destination. It is also notable that for lower modulation and higher FEC code rate, power requirement is less than higher modulation with lower FEC code rate. The reason being for BPSK, one symbol per sample with less redundancy bits needs more power rather than QPSK having two symbols per sample with more redundancy bits. Integrity of original data bits compels us to transmit more power so that they reach the destination with minimum error rate and loss.

For higher modulation schemes and code rates in DVB-S2, the modulation is higher which also increases the uplink power for link stability and normal operations.

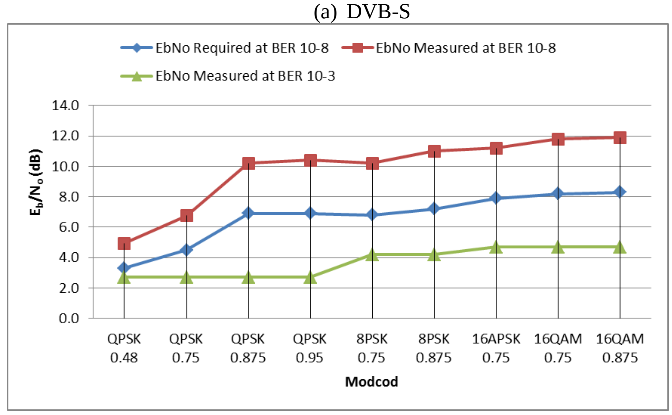
Figure 5 (a) & (b) shows same scenario of measured as well as calculated power through Satmaster pro software for Ku-band in DVB-S and DVB-S2. In Ku-Band rain attenuation has more effect than that of in C-band, so during raining or storms, Ku-band link can fluctuate which is also taken in consideration while calculating link budgets. In Ku-band, as in C-band, uplink power is directly proportional to the energy per bit for all type of carriers and different modulation schemes implemented keeping bit error rate constant.

C. Eb/No Measurement

Power is consumed according to energy per bit (Eb/No) ratings of modem. Eb/No is the measure of signal to noise ratio per bit and it compares the bit error rate performance without catering bandwidth efficiency. Different power requirement values for different Eb/No are shown according to modem module design. More Eb/No is required for higher code rates because redundant bits are less in higher data rates and there is need to push actual data to remote end. For every modulation scheme while using greater code rate the Eb/No requirement is much higher than higher modulation with lower code rate as depicted in Figure 6.



(a) DVB-S



(b) DVB-S2

Fig. 6. E_b/N_o

In Ku-band, like C-band, uplink power is directly proportional to the energy per bit for all type of carriers and different modulation schemes implemented keeping bit error rate constant [10]. If bit error rate (BER) is changed according to importance of link as shown in Table 3, then energy per bit can be normalized which effect required power for the transmitter to execute the link normally.

VI. CONCLUSION

Results indicated in this paper will play a vital role in bandwidth optimization both for Digital Video Broadcasting via satellite (DVB-S) and DVB-S2 satellite networks. Different receivers need different power to sustain link between two sites in terms of bit error rate and energy per bit and minimum power required for this link is termed as power stability. The comparison for different modulations and code rates shows that for DVB-S, the best configuration is QPSK

Table 3: Eb/No vs BER

Modulation	FEC code	Eb/No	BER
QPSK	0.75	3.8	1.0×10^{-6}
QPSK	0.75	4.5	1.0×10^{-8}
16APSK	0.75	4.3	2.2×10^{-3}
16APSK	0.75	5.2	4.5×10^{-4}
16APSK	0.75	5.9	7.0×10^{-5}
16APSK	0.75	6.4	1.6×10^{-5}
16APSK	0.75	6.5	2.5×10^{-6}
16APSK	0.75	6.5	2.5×10^{-6}
16APSK	0.75	7.9	1.0×10^{-8}

0.75 while in DVB-S2, the most suitable parameters are for 16APSK 0.75 in terms of power required while minimum BER can be achieved at energy per bit of 7.9dB. Bandwidth utilization comparison showed that as higher modulation and code rate is used, the required bandwidth is lesser. So best configuration is for 16QAM 0.875 in DVB-S2 while 8PSK 0.875 for DVB-S configuration. These results will also help satellite operators to keep their sources either in power limited or bandwidth limited mode providing best possible services to their customers.

Comparison of all the analyzed parameter can be drawn for both C and Ku band in future with low earth orbit (LEO) satellite and geostationary (GEO) satellite with Ka-Band and also for other modulation schemes.

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