Design of Higher Order Constellations for DVB-S2

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Abstract - DVB-S2 is the second generation specification for satellite applications. ACM functionality of DVB-S2 provides capacity gain of over 30% in comparison to its predecessor, DVB-S and has the potential to reduce the satellite capacity costs by upto 50%. Current DVB-S2 specifications go up to 32APSK constellation. This gives a parallelization of 5 bits. This paper attempts to design optimized constellations -64, 128 and 256, both symmetrical and asymmetrical ASPK. Accordingly, it suggests that 64APSK, symmetrical is a realizable proposition and should be taken up commercially.

Keywords: M-ary PSK, QAM, APSK, Symmetrical APSK, Asymmetrical APSK, Capacity,

I. INTRODUCTION

DVB-S2 is a transmission standard for high-speed satellite communication. Four different system configurations and application areas have been provided in the standard – broadcast (BS) services, interactive services, digital satellite news gathering (DSNG) and professional services (PS). Design objectives of any transmission system include maximum capacity. Information rate should be maximized while the BER/ PER at the receiver should be maintained within acceptable limits for quasi-error-free operation. Another criterion is spectral efficiency that is the transmitted bit rate per unit bandwidth. Spectral efficiency can be improved by increasing the order of modulations. The parameters of a transmission system include the transmitter power budget, available bandwidth for, MODCOD (type of modulation and the error correcting code rate). For DVB-S2, for quasi-error-free operation, a PER of 10-7 has been accepted in standards. It is required to design modulation constellations under the constraint of acceptable PER/ BER and allowable signal to noise ratio.

II. SATELLITE CHANNEL CHARACTERISTICS

The Satellite up-link is shared resource with multiple transmitters transmitting simultaneously. Satellite down-link for home users is a broadcast channel as each spot beam caters to thousands of home users simultaneously. Thus its modeling for information rate is to be done as a broadcast channel, with simplest analysis for a 2-user system. As each user exists at a different location within the spot beam coverage area and is affected probably differently by the weather phenomena, the received signal SNR is different for different users.

Satellite link (in Ku and Ka bands) is severely affected by the presence of clouds and other weather phenomena. The attenuation caused by these phenomena has been widely studied in various ITU-T models. This study can be applied to understand one component of channel variability. Further assuming a parabolic receiver dish antenna, the gain distribution with respect to the maximum gain (at the centre of the spot beam) can be studied. This provides the second reason for channel variability. Together the two can be combined to study the SNR distribution in the coverage area of satellite beam. A Satellite may operate in single carrier per transponder mode or in multiple carrier per transponder mode. In the first case, the high power amplifier (HPA) of the transponder can be driven to power efficient saturated operation mode. However, this introduces non-linearities in the satellite channel. When operating in multiple carriers per transponder mode, quasi-linear mode of HPA operation is preferred to avoid inter-channel interference.

Amplitude Phase Shift Keying (APSK) is suitable for digital transmission over nonlinear satellite channels due to its power and spectral efficiency combined with its inherent robustness against nonlinear distortion. Higher order M-ary modulation provides better spectral efficiency. APSK is suitable for digital transmission over non-linear channels (satellite broadcast channel with non-linear HPA characteristics). DVB-S2 proposes standardized 16APSK and 32APSK (non-hierarchical) constellations with parameters specified over a wide range of coding rate. There is a requirement for design optimization of higher order APSK (64, 128 and 256) along with the design optimization of hierarchical APSK (32, 64, 128, 256).

III. DVB-S2 MODULATION CONSTELLATIONS

Parallelism levels are – 2(QPSK), 3(8PSK), 4(16APSK) and 5(32APSK). Each parallel sequence is mapped into a constellation point based on the modulation used. QPSK and

8PSK are Gray encoded. Various constellation diagrams with relevant parameters are given below:

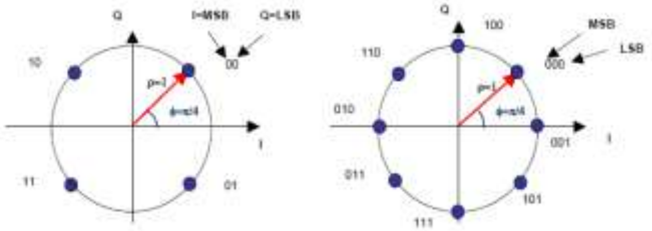

Figure 1 –QPSK and 8PSK constellations – DVB-S2

Normalised energy per symbol for QPSK, 8PSK (ρ^2)=1. Constellation points are symmetrically distributed over the circumference. 16APSK has one parameter (γ = R2/R1) while 32APSK has two parameters $(\gamma_1 = \frac{R2}{R1}, \gamma_2 = \frac{R3}{R1})$. Two constellation amplitudes are permitted – average energy per symbol = 1 or (R2 = 1 for 16APSK, R3=1 for 32APSK). These allow performance optimization according to channel characteristics (for example single or multiple carrier per transponder operation mode, use of non-linear pre-distortion, etc). Optimum constellation ratios for linear channel are tabulated below

TABLE 1 – Spectral efficiency of optimized 16APSK DVB-S2

Code Rate	Overall Spectral Efficiency	γ
2/3	2.66	3.15
¾	2.99	2.85
4/5	3.19	2.75
5/6	3.32	2.70
8/9	3.55	2.60
9/10	3.59	2.57

TABLE 2 - Spectral efficiency of optimized 16APSK DVB-S2

Code Rate	Overall Spectral Efficiency	γ_1	γ_2
¾	3.74	2.84	5.27
4/5	3.99	2.72	4.87
5/6	4.15	2.64	4.64
8/9	4.43	2.54	4.33
9/10	4.49	2.53	4.20

DVB-S2 constellations for 16APSK and 32APSK are given below

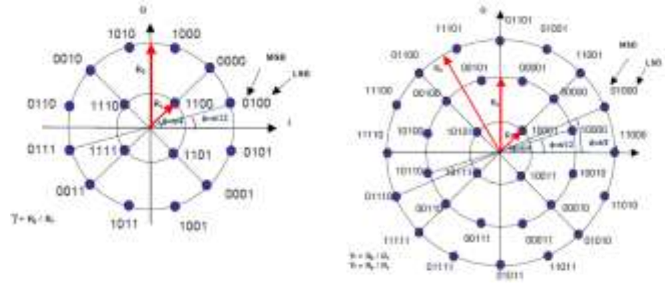

Figure 2 - 16APSK and 32APSK constellations - DVB-S2

For backward compatibility purpose, hierarchical 8APSK has also been specified in DVB-S2 standard. The constellation diagram for the same is given below

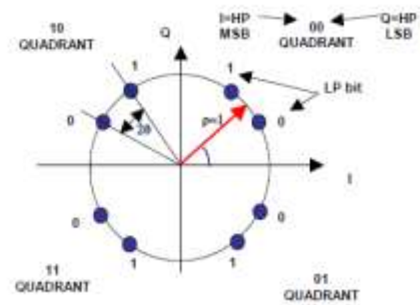

Figure 3 - Hierarchical/ Asymmetrical 8PSK DVB-S2

IV. LITERATURE SURVEY OF RELATED WORK ON MODULATION TECHNIQUES FOR DVB-S2

Haykins gives an excellent theoretical background on digital communication process on a noiseless and noisy channel is provided [1]. He describes conditions for distortion less transmission on a band limited noise-free communication channel and baseband shaping techniques. It further provides the error probability calculations for binary transmission over Gaussian channel .It describes digital modulation techniques and undertakes to describe their geometries in the signal constellation diagrams. It explains the union bound theorem for average probability of symbol error calculations. Finally, definitions for channel capacity and describes Shannon's channel coding theorem are provided.

A comprehensive survey of the transmission techniques used globally in digital television (TV) standards is presented in [9]. Criteria of bandwidth efficiency and acceptable video quality have been explored. A chronology of developments in television transmission is presented. European standards - DVB-T/T2 – terrestrial channel, DVB-S/S2 – satellite channel, DVB-C – cable and DVB-H – handheld have been described. American standards - terrestrial (ATSC) and hand-held (ATSC-M/H) have also been described. Digital

Broadcasting standards developed in Japan for Terrestrial (ISDB-T), Satellite (ISDB-S) transmission, International System for Digital Television (ISDTV), which was developed in Brazil by adopting the ISDB-T physical layer architecture are described next. China's Digital Terrestrial television Multimedia Broadcast (DTMB) has also been explained.

An excellent overview of DVB-S2 system has been given in [8]. Main features and performance in various scenarios and applications have been described. Underlying concepts of transmission performance, flexibility and reasonable receiver complexity have been explored. Discussion of channel coding and modulation is presented. Framing structure and synchronization have also been explained.

The optimization criteria for modulation constellation for mutual information maximization are described in [2]. It provides a description of APSK constellation. It describes the design criteria and further studies the properties of optimized constellations for equi-probable and non-equiprobable symbol constellations.

A constellation system compatible with DVB-S2 that uses non-equiprobable signals has been proposed in [3].

A variation of simulated annealing algorithm for optimizing two-dimensional constellations with 32 signals has been used in [4]. Symmetric pragmatic capacity has been optimized under peak-power constraint. Joint optimization of constellation and binary labeling is possible with this method. Performance of the optimized constellation over nonlinear satellite channel under additive white Gaussian noise has been analysed, with and without pre-distortion.

Idea of hierarchical modulation has also been studied in referece of DVB-S2. A hierarchical modulation scheme is proposed [5] to upgrade an existing digital broadcast system,. Basic (high priority) and secondary (low priority) are utilized. The combined bits for the two give overall constellation that can be transmitted over satellite channel. If the receiver is hierarchical, then the users can get both low and high priority data. In case of conventional non-hierarchical receiver, user can only receive high priority data. This provides an option of backward compatibility.

Application of hierarchical modulation in broadcasting systems has been described in [6]. Different receivers in broadcast system have different signal to noise ratios and accordingly different system error rates for the same transmitted system. Using hierarchical modulation, high priority information is mapped to more robust QPSK constellation that can be decoded by all users. However, total bits (high priority plus low priority) are mapped to higher order 16/ 32 – ary constellations and increase the information rate for receivers in good SNR condition.

Study on the noise immunity of DVB channels has been carried out in [7] when using higher-order M-ary APSK modulation schemes and concatenated BCH-LDPC codes. Dependencies to determine the probability at the decoder output are given taking into consideration the BCH and LDPC code parameters and the error probability in the communication channel. The influence of BCH packets length, the BCH code rate, the number of maximum iterations and the parameters of LDPC parity-check matrix on the code competence is analyzed. Study of the power of the concatenated LDPC-BCH code parameters on the radio channel noise immunity is conducted and dependencies to determine the required CNR at the input of the satellite receiver are given.

V. DESIGN OF APSK CONSTELLATIONS

The design attempts to maximize mutual information (information transmission rate and thus the spectral efficiency) with minimized error probability for a given average signal-to-noise ratio.

General M-ary APSK constellation can be described by a set of N concentric rings, with associated radii, $R_i = \gamma_i R_1, 1 \leq i \leq N, \gamma_1 = 1$, where R1 is the radius of innermost ring. There are n_i points in i-th ring so that $M = \sum_{i=1}^{N} n_i$. The system shall be termed as n1 + … + nN – APSK system. We assume that the radii are ordered so that R1 < R2 < ………..< RN

For symmetrical M-ary APSK, in the I-Q plane, M constellation points can be represented by the following set of equations

$$s_{ik} = R_i e^{j\left(\frac{2\pi k}{n_i} + \theta_i\right)}, 1 \leq i \leq N, 0 \leq k \leq n_i - 1$$

θ_i is the angle of first constellation point of i-th ring from the positive I-axis. Average symbol energy is given by

$$E_s = \frac{\sum_{i=1}^{N} n_i R_i^2}{M} = \frac{R_1^2}{M} \sum_{i=1}^{N} n_i \gamma_i^2$$

For asymmetrical APSK, 2θ represents the maximum angular separation between the constellation points on any ring in any quadrant. The set of equations is as given below

$$n_i = 4l_i,\ s_{ikq} = R_i e^{j\left(\frac{\pi}{4}+\frac{2k+1-l_i}{2}\theta_i+(q-1)\frac{\pi}{2}\right)}$$

$$2 \le i \le N, 0 \le k \le l_i - 1, 0 \le q \le 3, \quad \theta_i = \frac{2\theta}{l_i - 1},$$

N = no of rings, q = Quadrant no.

We maximize the mutual information of an AWGN channel for M equiprobable symbols. This provides the maximum transmission rate (bits/ channel use) at which error-free transmission is possible.

We have considered only non-hierarchical receiver. Accordingly we have used the term asymmetrical APSK wherever the angular separation between constellation points is not uniform. Optimization criteria for symmetrical and asymmetrical APSK is same and given below.

We assume equiprobable signal constellation. Representing all constellation points by $X = \{x_i : 0 \le i \le M-1\}$

$$I(X;Y) = \log_2 M - \frac{1}{M}\sum_{k=0}^{M-1} E\left[\log_2\left(\sum_{i=0}^{M-1} e^{-\left(\frac{E_s}{N_0}\left(|x_k+w-x_i|^2\right)-|w|^2\right)}\right)\right]$$

E[.] is the expectation over the normally distributed noise variable, w, with variance No and 0 mean. This expected value can be obtained using a Monte Carlo simulation. Also, all x_i have been normalized, so that

$$\frac{\sum_{i=0}^{M-1} x_i^2}{M} = 1$$

The optimization is done as $C = \max_{\rho,\varphi} I[X;Y]$

For the asymptotic case of $\frac{E_s}{N_0} \to \infty, C = \max_{\rho,\varphi} d_{min}^2$

d_{min} = constellation minimum distance.

VI. SIMULATION

Simulation for various constellations was carried out in Matlab. The constellation design was done for 64, 128 and 256-ary APSK for symmetrical modulation and 32/ 64 APSK for symmetrical APSK. We have used monte-carlo simulation for generating random noise. Also, we have considered 7.5 dB average coding gain for LDPC receiver so that we can compare the results of simulation with those given in DVB-S2 standard with both modulation and LDPC encoders used in simulation. Parameter variation is done for the no of constellation points in various rings, the radii of various rings and the angular separations. As the possible number of parameter sets become large as M increases and simulations become slow, radii ratios have been incremented in steps of 0.5

TABLE 3- Optimized parameters for Symmetrical 32APSK, 64APSK

Ring No	M=32			M=64		
	n_i	γ_i	θ_i	n_i	γ_i	θ_i
1.	4	1	π/4	4	1	π/4
2.	12	2.5	π/12	12	3	π/12
3.	16	4	0	24	5	0
4.	-	-	-	24	7	0

TABLE 4-Optimized parameters for Symmetrical 128APSK, 256APSK

Ring No	M=128			M=256		
	n_i	γ_i	θ_i	n_i	γ_i	θ_i
1.	4	1	π/4	4	1	π/4
2.	12	3	π/12	12	2.5	π/12
3.	24	5	0	20	4	0
4.	28	7	0	40	7	0
5	60	9.5	0	60	10	0
6	-	-	-	120	13	0

TABLE 5- Optimized parameters for asymmetrical 32APSK

Ring No	2θ = π/6		2θ = π/4		2θ = π/3	
	n_i	γ_i	n_i	γ_i	n_i	γ_i
1.	4	1	4	1	4	1
2.	12	3	12	2	12	2.5
3.	16	4	16	4	16	4

TABLE 6-Optimized parameters for asymmetrical 32APSK

Ring No	2θ = π/6		2θ = π/4		2θ = π/3	
	n_i	γ_i	n_i	γ_i	n_i	γ_i
1.	4	1	4	1	4	1
2.	12	3	12	3	12	3
3.	24	5	16	5	24	5
4	24	7	32	7	24	7

Average probability of symbol error (SER) for various simulated modulates for vs. Eb/No is plotted below. The plot for simulated 32APSK matches with the DVB-S2 symmetrical 32APSK at around 9 dB Eb/No (around 16 dB Es/No) for rate 9/10 LDPC coding.

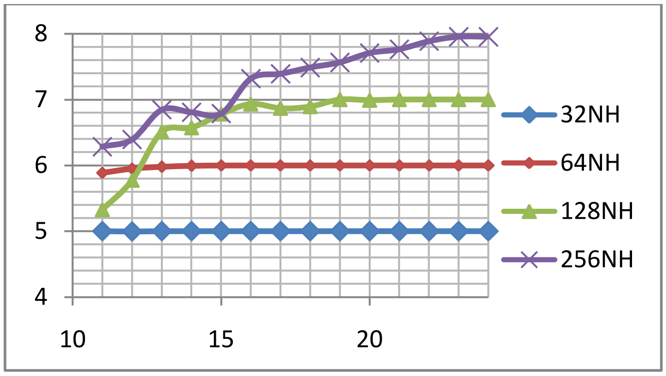

Figure 4- Capacity vs. Eb/No for various symmetrical simulated APSK Constellations

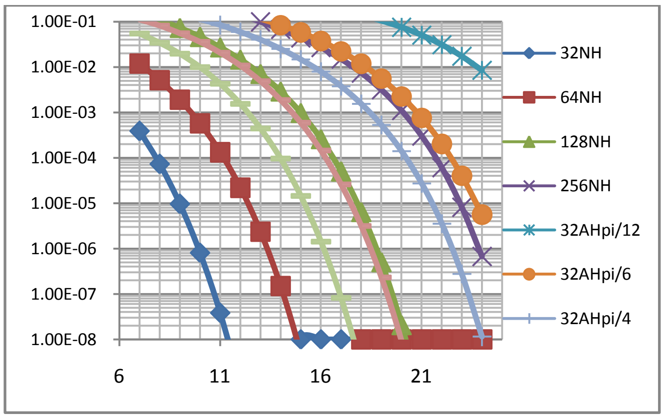

Figure 5-Average SER vs Eb/No Plots for various optimized modulation schemes

VII. CONCLUSION

From the SER plots of simulated constellations, it seems evident that symmetrical 64APSK is an immediate possibility for commercial use in DVB-S2 with around 4 -5 dB of additional SNR requirement. Another possibility may be asymmetrical 32APSK with $2\theta = 5\pi/12$. This may be slightly more useful for hierarchical receivers where it shall provide some advantage to the high priority stream. Other constellations at present seem too demanding due to high energy to noise ratio requirements.

VIII. FUTURE SCOPES

Symmetrical 64APSK and asymmetrical 32APSK seem viable commercial options. The authors intend to fine tune current simulations. They also intend to do further simulations including LDPC to improve accuracy of results. Further, authors intend to design a truly hierarchical 32APSK constellation with 2 HP and 3 LP bits where the constellations for both are optimized and still the overall constellation is a 32APSK constellation suitable for satellite communication.

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