REVIEW OF DVB-S2 SYSTEM AND ITS LDPC CODING

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Abstract—**Satellite networks are lucrative because of wide coverage, speed of deployment of user terminal and virtual non-existence of wired networks in difficult terrains. DVB-S2 is the new standard for digital video broadcast for fixed user with 30% capacity increase over DVB-S. It also supports interactive services including IP unicast and digital satellite news gathering. As satellite network is characterized by low received power, it requires most powerful coding techniques for significant coding gains. This study gives a broad view of DVB-S2, services envisaged, channel coding requirements for satellite fixed broadcast services, justification of using LDPC codes, description of LDPC codes, details of LDPC codes and expected performance of broadcast system using these codes. This study shall be as the basis of software simulation of the LDPC encoding and decoding algorithms used in DVB-S2 as well as the others available in literature and compare their performances for the simulated broadcast scenarios. The comparison metric shall include coding gains, encoding & decoding complexity, encoding & decoding time and requirement of resources for encoding & decoding.**

Keywords—**DVB-S, DVB-S2, CCM, ACM, VCM, BS, FEC, LDPC,IP Unicast, DSNG, Coding Gain**

I. INTRODUCTION

Satellite broadcasting allows coverage of large areas. Digital Video Broadcast (DVB) specifications cover digital satellite services via cable, satellite and terrestrial transmitters. Satellite member of DVB family that is DVB-S [1] describes modulation and channel coding system for satellite digital TV (standard and high definition) services to be used for primary and secondary distribution in Fixed Satellite Service (FSS) and Broadcast Satellite Service (BSS) bands. Direct Broadcast Services (DBS) is satellite television service intended for home users, operating in Ku-band (12GHz).

Digital Video Broadcast – Second Generation (DVB-S2) [2] is a successor of DVB-S, which not only increases capacity for broadcast but also envisages new services. It defines four system configurations and application areas – broadcast services, interactive services, digital satellite news gathering and professional services. It is a successor of the popular DVB-S broadcast system. DVB-S2 is envisaged for broadcast services including standard and high definition television, interactive services including internet access and professional data content distribution. DVB-S2 uses Low Density Parity Check codes (LDPC). LDPC codes [3] are a class of linear block codes used for Forward Error Correction (FEC), which can approach Shannon's capacity within fraction of a decibel.

II. DVB-S2 AND ITS SUB-SYSTEMS

DVB-S2 sub-systems use mode adaptation functional block, stream adaptation functional block, FEC encoding block, bit-to-constellation mapping functional block, physical layer (PL) framing functional block and finally the modulation block.

Mode adaptation block provides input stream interfacing, (optional) input stream synchronization, null-packet detection for Adaptive Coding and Modulation (ACM) and Transport stream input formats, Cyclic redundancy check (CRC-8) coding for error detection at packet level at the receiver for packetized input streams, merging of input streams for multiple input stream modes and slicing into data fields. A base-band header is appended in front of Data Field. The outputs of mode adaptation functional block are baseband frames. Stream adaption is then applied to provide padding to complete a baseband frame and baseband scrambling.

FEC functional block concatenates BCH outer codes and LDPC inner codes. Depending on the application area, 64800 bits blocks or 16200 bits blocks are used in LDPC coding. A number of code rates, ranging from ¼ to 9/10 have been proposed that depends on the environment or channel conditions. Features of Variable Coding and Modulation (VCM) and ACM allow frame-to-frame variation of coding. However, within a frame, this needs to be fixed. The coder output is given to a mapper that maps it to QPSK, 8PSK, 16PSK and 32APSK constellations. For QPSK and 8PSK, gray mapping is used.

PL framing provides dummy PL frame insertion, PL signaling, optional pilot symbol insertion and PL scrambling of energy dispersal. Dummy PL frames are transmitted in absence of useful data. System provides a regular physical layer framing structure based on slots of 90 modulated symbols, to allow receiver synchronization on FEC block structure. A slot is dedicated to physical layer signaling, including start-of-frame (SOF) limitation and transmission mode definition. Carrier recovery in receiver can be facilitated by introducing regular raster of pilot symbols. A pilotless transmission is also possible, increasing available capacity by 2-4%. Band-shaping filtering and quadrature modulation is then applied to generate final RF signal.

III. DVB-S2 BROADCAST SERVICES (BS)

DVB-S2 is intended to provide Direct-to-Home (DTH) services for consumer Integrated Receiver Decoder (IRD), as well as collective antenna systems (Satellite Mast Antenna Television – SMATV). Services include digital multi-program television (TV) and high definition television (HDTV) broadcast. Broadcast services are transported in MPEG stream format. VCM may be applied on multiple transport streams to achieve differentiated error protection for different services (TV, HDTV, audio and multimedia). Non backward compatible (NBC-BS) and backward compatible (BC-BS) with

DBV-S modes are available. Backward compatible modes may be used to extend services delivered by a transponder, without disturbing legacy DVB-S receivers.

Test results have confirmed capacity gains in excess of 30% for DVB-S2 over DVB-S for SDTV broadcasting.

IV. DVB-S2 INTERACTIVE SERVICES (IS)

These are intended to provide interactive data services including internet access, to customer IRDs and personal computers. Return path interactivity is possible via terrestrial connection through telephone lines or via satellite. Return link specifications include DVB-RCS [4], DVB-RCP, DVB-RCG, and DVB-RCC. With return channel informing the transmitter of actual receiving conditions, transmission parameters may be optimized for each individual user, depending on path conditions. Data services are transported in single or multiple transport stream format or single or multiple generic stream format. Constant coding and modulation (CCM) and ACM are both allowed. Using ACM, each individual satellite receiving station controls the protection mode of the traffic addressed to it.

IP unicast links using DVB-S2 must adapt error protection on a per-user basis, where the number of users may be potentially upto hundreds of thousands. IP packet prioritization must be applied at ACM router to counter temporary excess of available channel capacity.

V. DVB-S2 DIGITAL TV CONTRIBUTION AND SATELLITE NEWS GATHERING (DTCV/DSNG)

These applications consist of point-to-point or point-to-multipoint transmissions, connecting fixed or transportable uplink and receiving stations. These are not intended for reception by general public. Services are transported in single or multiple MPEG transport stream format. Both CCM and ACM are possible. When using ACM, a single satellite receiving station typically controls the protection mode of the full multiplex.

VI. DVB-S2 DATA CONTENT DISTRIBUTION/TRUNKING AND OTHER PROFESSIONAL SERVICES (PS)

These are mainly point-to-point or point-to-multipoint service, including interactive services to professional head-ends, which redistribute services over other media. Services are transported in single or multiple generic stream format. The system can provide CCM, VCM or ACM.

VII. CODING AND MODULATION REQUIREMENTS IN SATELLITE COMMUNICATION

Broadcast satellite channels typically use Ku-band (12 GHz). At these frequencies, the biggest atmospheric impairment is rain attenuation. Other effects for fixed terminals include shadowing by obstacles, impacting line-of-sight (LOS) communication. Large free space loss (FSL) due to very large distance between geostationary satellites and the subscriber terminal, results in very low received power. This calls for powerful error correcting codes to provide large coding gains. For satellite communication channels, additive white Gaussian nose (AWGN) is normally assumed [4]. The use of advanced channel coding schemes (turbo codes and LDPC codes) is the state-of-the-art technology used in current satellite systems to provide broadcast services to fixed terminals in Ku/Ka frequency bands, using DVB-S2 in forward link and DVB-RCS in return link. DVB-S2 uses LDPC codes while DVB-RCS uses duo-binary turbo codes.

Any code should perform close to the channel capacity with moderate decoding complexity and for arbitrary value of block size and coding rate. LDPC codes with large block sizes are capable of achieving these requirements. LDPC codes outperform turbo codes in error floor and code rate selection requirements. Irregular Repeat-accumulate (IRA) LDPC codes result in manageable encoding complexity. LDPC codes can achieve higher throughputs than turbo codes, if parallel decoding architectures are allowed. Also, turbo codes are patented while LDPC codes are not patented.

VIII. LDPC CODES

LDPC codes belong to a broad family of error-controlling codes known as compound codes. Advantages of LDPC codes include absence of low-weight code words and iterative coding of low complexity. In Turbo codes (another FEC codes and competitor of LDPC codes), presence of a small number of low-weight code words results into code words close to each other and error floors. LDPC codes provide construction techniques without low-weight code words, resulting into vanishingly small bit error rates. Further, decoders of LDPC codes are of manageable complexity.

LDPC codes are characterized by parity-check matrices that are sparse, that is they consist mainly of zeros and only a small number of ones. Structure of LPDC codes is well portrayed by bipartite graphs. A bipartite graph [5] is constructed with sets of variable nodes and check nodes. Variable nodes correspond to the elements of code words. Check node correspond to the set of parity check constraints satisfied by code words in the code. For regular LDPC codes, all nodes of similar type have exactly the same degree. As block length of the code approaches infinity, each check node is connected to a vanishingly small fraction of variable nodes, resulting in the term low-density.

Practical block lengths of LDPC code are large, ranging from thousands to millions of bits. Accordingly, statistical analysis of ensemble of LDPC codes, rather than algebraic analysis is more common. This allows making statistical statements about certain properties of member codes and the ensemble. Minimum distance property of member codes within the ensemble is of great interest. For an ensemble, it is a random variable. As the block length of an ensemble of LDPC code increases, practically all member codes have minimum distance bound by a fraction of the code length. There is high probability of finding a suitable LDPC code by random selection from the ensemble. Regular LDPC present less decoding complexity compared to turbo codes. They however, do not appear to come as close to Shannon's limit as their turbo code counterpart. Irregular LDPC codes [6] are constructed by choosing degrees of variable and check nodes according to some distribution. Irregular LDPC codes outperform regular turbo codes in their proximity to Shannon's limit.

LDPC codes have made it possible to achieve coding gains of the order of 10 dB. These coding gains can be exploited to extend the range of digital communication receivers, substantially increase bit rates of digital communication systems or to significantly decrease the transmitted signal energy per symbol.

IX. EARLIER WORK ON LDPC CODES

LDPC codes were first introduced by Gallager. Gallager used a graphical representation of the bit and parity-check sets of regular LDPC codes to iterative coding. He formalized the use of bipartite graphs for describing families of codes. Irregular LDPC codes were proposed by researchers in 90's. These codes are capable of producing performance within a fraction of a decibel from Shannon constrained channel capacity [7]

MacKay and Neal provided an LDPC encoding algorithm. Gallager and MacKay also provided pseudo-random construction of LDPC codes. Current design techniques for LDPC codes enable construction of codes that approach Shannon's capacity within hundredth of a decibel. Gallager also first proposed decoding of LDPC codes using message passing algorithms. Density evolution analysis of message passing decoding first appeared in Gallager's work. Luby, Mitzermaker and Shokrollahi first proposed density evolution analysis of irregular codes used on a binary erasure channel [8].Mackey and Neal demonstrated the effects of cycles on practical performance of LDPC codes through computer simulations and also beneficial effects of using graphs. Tanner recognized the importance of cycle-free graphs in the context of iterative coding by proving convergence of the sum-product algorithm for codes whose graphs are cycle free. Proietti, Tellatar, Richardson and Urbanke introduced stopping sets and used these to develop analysis of finite length LDPC ensembles [9]. Vontobel provided analysis on pseudo-random code-words. Townsend and Weldon first presented quasi-cyclic codes [10].

Construction of LDPC codes based on designs, partial geometries and generalized quadrangles is also well considered in the literature. Graph based codes with good girth have been presented by Marguli [11]. and extended further. Other constructions for LDPC codes that are a mixture of algebraic and randomly constructed portions have also been given.

Tanner found the algebraic methods for constructing graphs suitable for sum-product decoding. Karplus and Krit first implemented length-73 finite geometry code on an IC using iterative decoding [12].

X. LDPC CODES IN DVB-S2 AND THEIR PERFORMANCE

LDPC together with outer Bose-Chaudhari-Hocquenghem (BCH) outer codes, DVB-S2 standard achieves outstanding error correction performance. Various LDPC code length used under different environments include 16200 bits and 64800 bits block-sizes with different code rates.

LDPC code in DVB-S2 has normal frames with code word length of 64800 bits and short frames with 16200 bits. DVB-S2 LDPC codes are encoded as irregular repeat accumulate (IRA) codes, with have advantage of low encoding complexity. In general, generator matrices are needed for encoding. Even though, the parity check matrix is sparse for LDPC, generator matrix may not be so, leading to storage and complexity problems since standardized codes are very long. To facilitate description of codes and for easy encoding, certain structures have been imposed on the parity check matrices of DVB-S2 LDPC codes. Restricting a sub-matrix of the parity check matrix to be lower triangular eliminates the need to derive a generator matrix and leads to linear encoding complexity.

In DVB-S2, a wide range of bandwidth efficiency from 0.5 bits/symbol to 4.5 bits/ symbol is covered by defining ten different code rates starting from ¼ upto 9/10, with four different modulation schemes QPSK, 8PSK, 16APSK and 32APSK. The codes have been optimized for broadcast mode. For each code rate, a parity check matrix is specified by listing adjacent check nodes for the first bit node in a group of 360. Coded block length is 64800 for all rates in broadcast mode. To improve performance, irregular LDPC codes are used where degrees of bit nodes are varying. Table showing number of bit nodes of various degrees is given below for 64800 bit block length.

Code Rate	13	12	11	8	4	3	2	1
1/4		5 400				10 800	48 599	1
1/3		7 200				14 400	43 199	1
1/2				12 960		19 440	32 399	1
3/5		12 960				25 920	25 919	1
2/3	4 320					38 880	21 599	1
3/4		5 400				43 200	16 199	1
4/5			6 480			45 360	12 959	1
5/6	5 400					48 600	10 799	1
8/9					7 200	50 400	7 199	1
9/10					6 480	51 840	6 479	1

For non-broadcast applications, a set of codes with 16200 bit blocks have been generated, with listing of adjacent check nodes in group of 360. Corresponding table is given below.

Code Rate	13	12	11	8	4	3	2	1
1/5		360				2 880	12 959	1
1/3		1 800				3 600	10 799	1
2/5		2 160				4 320	9 719	1
4/9				1 800		5 400	7 999	1
3/5		3 240				6 480	6 479	1
2/3	1 080					9 720	5 399	1
11/15		360				11 520	4 319	1
7/9						12 600	3 599	1
37/45	360					12 960	2 879	1
8/9					1 800	12 600	1 799	1

Design of LDPC codes in DVB-S2 is restricted to structured parity check matrix. Still, performance is very good due to careful choice of check node/ bit node connections. To meet the error rate requirements of DVB-S2 (packet error rate of 10^{-7}), an outer BCH code with the same block length as LDPC frame and an error correction capability of upto 12 bits is used.

XI. CONCLUSION

Satellite broadcast provides wide coverage, ease and speed of installation of earth terminals and accessibility in difficult terrains. DVB-S2 standard improves satellite broadcast by increasing the capacity in excess of 30%. This means more number of satellite user channels with the same transponder bandwidth. DVB-S2 also provides possibility of a long-term migration plan by providing backward compatibility with DVB-S. DVB-S2 adds interactive data services such as IP unicast, making possibility of access of these services to remote and difficult terrains or in emergency scenarios. Various return channel possibilities are available, including low data rate telephone connection or return-link via satellite where there is no wired connection at all. Availability of ACM on per user basis for interactive services results in capacity enhancement well in excess of 30%. Overall, DVB-S2 is a technology to stay in long term.

Extremely low received power in satellite networks calls for extremely powerful coding techniques with excellent coding gains. However, they require it with manageable encoding and decoding complexity for commercial viability. DVB-S2 realizes the same by using LDPC codes of large block lengths. These codes with the design restrictions imposed on them in DVB-S2 scenario have given very good simulation results.

XII. FUTURE WORK

It is proposed to implement various algorithms available in literature for encoding and decoding of LDPC codes, including those specified in DVB-S2. It is further proposed to test these under various possible broadcast scenarios for different terrains and geographies. This shall include simulation of channel models and various subsystems of DVB-S2. Comparison of the same with the performance results published DVB-S2 standard shall be carried out. Various algorithms shall be evaluated for block lengths, encoding & decoding complexity, and encoding & decoding under the condition of similar performance and coding gains. In doing so, it is proposed to work towards developing an overall metric for assessment of various LDPC code ensembles and optimization of proposed codes in DVB-S2.

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