Analysis of Reed-Solomon Codes and Their Application to Digital Video Broadcasting Systems

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Slide 1. Overview

- In this paper, we analyzed decoding algorithms that correct both errors and erasures for Reed-Solomon (RS) codes based on a factorization along with the Berlekamp–Massey (BM) algorithm.
- We presented and discussed implementation of RS codes in Digital Video Broadcasting (DVB) standards and provided brief reviews of new DVB-H standards.
- Analysis and simulation of symbol error rate (SER) versus output SER for RS codes used for multi-protocol encapsulation - forward error correction (FEC). Block in DVB-H was conducted.

Slide 2. Introduction

- Reed-Solomon (RS) code for correcting errors and erasures provides improved performance in various environments, including space communication, compact disc audio system, ISDN and Digital Video Broadcasting (DVB).
- Error occurs in data streams when some data element is corrupted; many errors occur when data elements are missing or inserted for the decoder to find them.
- Simultaneous error correction involves adding error correction information at the source that can be recovered from.
- Error-correction capability of any RS code is determined by k, the number of redundant symbols added to block.
- Since there is a block output symbol beyond error correction, additional symbols can be added to block input symbol to improve the code performance and reliability.
- RS code for decoding is used in multi-protocol encapsulation, and factorization algorithms can be useful for solving Berlekamp’s key equation for decoding RS codes.

Slide 3. Introduction (Cont’d)

- Forney defined error locator polynomial, using Forney syndromes, to correct both errors and erasures for RS codes.
- Based on Forney’s ideas, various authors have developed simplified algorithms for RS code correction.
- Recently, inverse-free method was proposed to simplify RS algorithm for finding error locator polynomial in RS decoder to correct both errors and erasures.
- Sherman’s basic theorem on coding states that correct e errors, data stream must guarantee minimum distance between correct data streams of at least 2e+1, to detect e errors, or correct e erasures, valid entries in data stream must be separated by at least e+1 bits.
- Reed and Solomon devised method for constructing linear codes over finite fields, where individual data elements can be represented with elements of finite field.
- For digital data, Galois fields GF(2^n), for n = 8, 16, or 32, should be considered, where underlying data words are single octets, pairs of octets, or quads of octets.

Slide 4. Interfacing and Enhanced Forward Error Correction

- In DVB-H with other DVB/BM/transport streams and based on DVB Transport Stream (DVB-TS) formatized by seven groups of the MPE-2 standard; DVB systems in based on Internet Protocol (IP).
- Using IP allows coding to be decoupled from transport, supports multiple networks that benefit bandwidth-rich terminals providing various applications and services, typically does not require new protocol infrastructure, and is related to standard and improved IP protocols.
- DVB-H is suitable for handheld mobile terminals and low-cost transmission.
- IP can be used in multimedia communications over IP or DVB-H may be preferred application service interface, but both use time sharing and MPE-FEC is used for DVB-H.
- In DVB systems, EH and DVB-H has been used for multiple transport streams, allowing interworking with DVB-T.
- IP data are encapsulated into transport streams over DVB transport stream protocol defined in DVB standards.

Slide 5. IP Interfacing and Enhanced Forward Error Correction (Cont’d)

- On MPE level, additional stage of forward error correction (FEC) is added.
- This scheme is used to improve robustness and mobility of signal.
- Technique called MPE-FEC is a second main innovation of DVB-H besides time slicing.
- MPE-FEC complements physical layer FEC of underlying DVB-T standard.
- It is intended to reduce the S/N requirements for handheld device reception.
- MPE-FEC processing is located on link layer or IP input streams level before they are processed in the network.
- MPE-FEC, MPE, and time slicing methods were defined together and directly aligned with each other.
- All three elements manually form DVB-H code which contains essential DVB-H functionality as shown in Figure 1.

Slide 6. IP Interfacing and Enhanced Forward Error Correction (Cont’d)

- Figure 1. Diagram of DVB-H Code and Transmitter

Slide 7. IP Interfacing and Enhanced Forward Error Correction (Cont’d)

- IP input streams provided by different sources as individual elementary streams are multiplexed according to time slicing method.
- MPE-FEC error protection is calculated separately for each individual elementary stream.
- IP packets encapsulation and embedding into transport stream follow.
- All relevant data processing is performed before transport stream interface in order to guarantee compatibility to DVB-1 transmission network.
- All streams together form DVB-H code which contains essential DVB-H functionality.
- Now, MPE/FEC scheme consists of RS code in conjunction with block interleaver.
- MPE-FEC encoder creates specific frame structure (FEC frame), inserting incoming data to DVB-H code as demonstrated in Figure 2.

Slide 8. IP Interfacing and Enhanced Forward Error Correction (Cont’d)

- Figure 2. MPE-FEC frames structure

Slide 9. IP Interfacing and Enhanced Forward Error Correction (Cont’d)

- FEC frame consists of minimum of 1003 rows and constant number of 215 columns; every frame cell corresponds to one byte.
- Frame is separated into two parts, application data table on the left (19 columns) and RS data table on the right (44 columns).
- Application data table is filled up with IP packets of service to be protected.
- After applying RS, (253, 181) code to application data row-by-row, it is possible to correct two errors in RS code.
- After coding, IP packets are read out of application data table and encapsulated in IP packets using MPE method.
- These application data are followed by parity data which are read out of RS data table column-by-column and encapsulated in separate FEC sections.
- FEC frame structure also contains “virtual” block interleaving effect in addition to coding.

Slide 10. Simulation and Results

- To evaluate proposed RS codes, we have performed simulations with use of MATLAB
- Figures below show input SER versus output SER for RS code used for MPE-FEC block in DVB-H.
- Code takes 93 bytes, adds 64 parity bytes of redundancy and through cyclic redundancy checksum (CRC) in MPE-FEC packet header.
- MPE-FEC packet contents are written as same time, where CRC check fails.
- If MPE-FEC packet contents are unreadable, byte-in-parity packet are defined “truncated” symbols, and using ones; “0”s allows decoder to correct twice more bytes that could be corrected when erasures were missed.
- So, if errors are present, code can correct up to 64 bytes out of 255-bits codeword.

Slide 11. Simulation and Results (Cont’d)

- Figures 3 and 4 show only SER transfer function (output for given input) of descriptors that shown strong noise strength of RS coding, especially 255, 191, 64/60 code for MPE-FEC used in DVB-H.
- Figures 5 and 6 show output SER versus input SER for (204, 191, 8) RS code and code used for DVB-H with DVB.
- Code takes 108 bytes, encodes them by adding 16 parity bytes, does not use erasures and correct any 8 bytes of 204-byte codeword.

Slide 12. Simulation and Results (Cont’d)

- Figures 7 and 8 show only SER transfer function (output for given input) of descriptors that shown strong noise strength of RS coding, especially 255, 191, 64/60 code for MPE-FEC used in DVB-H.
- Figures 9 and 10 show output SER versus input SER for (204, 191, 8) RS code and code used for DVB-H with DVB.
- Code takes 108 bytes, encodes them by adding 16 parity bytes, does not use erasures and correct any 8 bytes of 204-byte codeword.

Slide 13. Simulation and Results (Cont’d)

- Figures 11 and 12 show only SER transfer function (output for given input) of descriptors that shown strong noise strength of RS coding, especially 255, 191, 64/60 code for MPE-FEC used in DVB-H.
- Figures 13 and 14 show output SER versus input SER for (204, 191, 8) RS code and code used for DVB-H with DVB.
- Code takes 108 bytes, encodes them by adding 16 parity bytes, does not use erasures and correct any 8 bytes of 204-byte codeword.

Slide 14. Simulation and Results (Cont’d)

- Figures 15 and 16 show only SER transfer function (output for given input) of descriptors that shown strong noise strength of RS coding, especially 255, 191, 64/60 code for MPE-FEC used in DVB-H.
- Figures 17 and 18 show output SER versus input SER for (204, 191, 8) RS code and code used for DVB-H with DVB.
- Code takes 108 bytes, encodes them by adding 16 parity bytes, does not use erasures and correct any 8 bytes of 204-byte codeword.

Slide 15. Simulation and Results (Cont’d)

- Figures 19 and 20 show only SER transfer function (output for given input) of descriptors that shown strong noise strength of RS coding, especially 255, 191, 64/60 code for MPE-FEC used in DVB-H.
- Figures 21 and 22 show output SER versus input SER for (204, 191, 8) RS code and code used for DVB-H with DVB.
- Code takes 108 bytes, encodes them by adding 16 parity bytes, does not use erasures and correct any 8 bytes of 204-byte codeword.

Slide 16. Findings and Conclusions

- In conclusion, we should note that on 64 bytes can be corrected, regardless whether errors exist in one or all eight bits.
- Figures 1-20 show that all evaluated codeshow a significant level of error correction on input errors, but the degree of error correction varies significantly from code to code and from one-bit errors to multiple-bit errors.
- All codes were tested with short-term bursts of errors to simulate typical channel conditions.
- The results were compared to existing RS codes and showed that the proposed codes outperform the existing ones in most cases.
- The proposed codes are suitable for real-time applications and can be used in various scenarios requiring robust error correction.
- The codes were also tested with varying bit error rates and showed a high level of robustness.
- The proposed codes are suitable for use in digital video broadcasting systems, where reliability is of utmost importance.

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