



**Claudio Alejandro Szabas**

**Fountain Codes and other Channel Coding  
Schemes for Protection of Transport Streams  
over IP networks With Packet Erasure**

**Dissertação de Mestrado**

Dissertation presented to the Postgraduate Program in  
Electrical Engineering of the Departamento de Engenharia  
Elétrica, PUC-Rio as partial fulfillment of the requirements for  
the degree of Mestre em Engenharia Elétrica.

Advisor: Prof. Weiler Alves Finamore

Rio de Janeiro

February 2011



**Claudio Alejandro Szabas**

**Fountain Codes and other Channel Coding  
Schemes for Protection of Transport Streams  
over IP networks With Packet Erasure**

Dissertation to the presented Postgraduate Program in  
Electrical Engineering, of the Departamento de Engenharia  
Elétrica do Centro Técnico Científico da PUC-Rio, as partial  
fulfillment of the requirements for the degree of Mestre.

**Prof. Weiler Alves Finamore**  
**Advisor**

Centro de Estudos em Telecomunicações - PUC-Rio

**Prof. Marco Antonio Grivet Mattoso Maia**

Centro de Estudos em Telecomunicações - PUC-Rio

**Prof. Alessandro James Salvaterra Dutra**  
UFRJ

**Prof. José Eugenio Leal**  
Coordinator of the Centro  
Técnico Científico - PUC-Rio

Rio de Janeiro, 25 de fevereiro de 2011

All rights reserved.

### Claudio Alejandro Szabas

Claudio Alejandro Szabas Graduated from the State University of Rio de Janeiro in 2005. He started in the Broadcast Industry almost 7 years ago and worked for a large scale television company in Brazil and leading broadcast technology developers from US and Canada. Over the past 2 years he has been managing broadcast projects in many countries in Latin America, which involve transport and monitoring of high quality video over IP.

#### Bibliographic data

Szabas, Claudio Alejandro

Fountain and other channel coding schemes for protection of Transport Streams over IP networks with packet erasure / Claudio Alejandro Szabas ; adviser: Weiler Alves Finamore. — Rio de Janeiro : PUC-Rio, Department of Electrical Engineering, 2011.

v., 82 f: il. ; 29,7 cm

1. MSc Dissertation - Pontifícia Universidade Católica do Rio de Janeiro, Department of Electrical Engineering.

Bibliography included.

1. Electrical Engineering – Dissertation. 2. Fountain Codes. 3. Real-Time Transport Protocol (RTP). 4. User Datagram Protocol (UDP). 5. Reed-Solomon. 6. MPEG-2 Transport Streams. I. Alves Finamore, Weiler. II. Pontifícia Universidade Católica do Rio de Janeiro. Department of Electrical Engineering. III. Title.

CDD: 510

## Acknowledgments

To my parents Claudio and Luci, my example of hard work, commitment and dedication.

To my Professor Weiler Finamore, who provided me with great orientation.

To my colleagues at Miranda Technologies, TV Globo and Globosat, for the experience and learning employed herein.

## Abstract

Szabas, Claudio Alejandro; Finamore, Weiler Alves (Advisor). **Fountain codes and other channel coding schemes for Protection of Transport Streams over IP Networks with Packet erasure**. Rio de Janeiro, 2011. 82p. MSc Dissertation – Departamento de Engenharia Elétrica. Pontifícia Universidade Católica do Rio de Janeiro.

There is a growing demand for the transport of video over IP today, i.e., for content distribution over the Internet, IPTV services in Standard and High Definition, or even inside traditional broadcasters' networks, transporting broadcast quality contributions to the main program. In such applications, the source encoded MPEG-2 or -4 content is transported in the form of *MPEG-2 Transport Streams*, encapsulated over network protocols. However, IP networks, which can be modeled as *Packet Erasure Networks* (PEC), were not originally designed for the transport of real time media. There are problems, such as packet drops and jitter, which generate severe impairments in the content that is decoded at the reception. Traditional methods for overcoming these problems, as for example retransmissions performed by *Automatic Repeat Request* (ARQ) protocols, are not suitable for real-time multimedia protection. Channel coding is the solution of choice for protecting real-time multimedia over IP. There are channel coding schemes specified in open recommendations and Standards, widely adopted by equipment vendors today. *Fountain Codes* present very attractive characteristics for the transport of real-time multimedia. In the present work, simulations with a Fountain code, protecting Transport Stream contents prior to network encapsulation, are presented. The experiment is repeated with other channel coding techniques commonly employed today. In order to analyze the decoded contents and obtain comparative results, standardized Transport Stream measurements, objective *Blocking Artifacts* measurements and subjective analysis of the decoded samples are employed. This work is concluded with the proposal of a *Transport Stream Adaptive channel encoder*, that is explained in Appendix-B.

## Keywords

Fountain Codes, Real-Time Transport Protocol (RTP); User Datagram Protocol (UDP); Reed-Solomon; MPEG-2 Transport Streams.

## Resumo

Szabas, Claudio Alejandro; Finamore, Weiler Alves (Orientador). **Códigos Fontanais e outros esquemas de codificação de canal para proteção de Transport Streams em redes IP com apagamento de Pacotes**. Rio de Janeiro, 2011. 82p. Dissertação de Mestrado – Departamento de Engenharia Elétrica. Pontifícia Universidade Católica do Rio de Janeiro.

Há, nos dias atuais, uma crescente demanda pelo transporte de vídeo sobre IP, i.e., para distribuição de conteúdo pela Internet, por serviços de IPTV em definição padrão e em alta definição e, mesmo para uso interno nas redes de emissoras tradicionais de televisão, que transportam contribuições de elevada qualidade para seus programas. Em tais aplicações, o conteúdo dos programas é transportado usando MPEG-2 ou MPEG-4, sob a forma de MPEG-2 Transport Streams, encapsulados com protocolos tais como RTP, UDP e IP. As redes IP, que são modelizadas como Redes com Apagamento de Pacotes (PEC) não foram, no entanto, concebidas para o transporte de mídias em tempo real, esbarra portanto em problemas comuns como perdas de pacotes e jitter, gerando perturbações que se refletem na recepção do conteúdo. Os métodos tradicionais para superar estas dificuldades, como por exemplo, os que se baseiam em retransmissões usando protocolos ARQ (Automatic Repeat on Request), não são uma solução eficiente para proteger a transmissão de multimídia em tempo real. A proteção de multimídia transmitida em tempo real via IP recorre, neste caso, aos códigos para canal. Há códigos para canal recomendados em RFC's e Padrões, usados amplamente pelos fabricantes de equipamento. Os modernos Códigos Fontanais, possuem características atraentes para o transporte de conteúdos multimídia em tempo real. Neste trabalho, simulações são realizadas, onde o conteúdo encapsulado em Transport Stream, é protegido com Códigos Fontanais antes do encapsulamento para o envio através da rede. A título de comparação, o experimento é realizado também usando outros códigos para canal recomendados. Para realizar a comparação são usadas medições padronizadas do Transport Stream, medições objetivas como artefatos de bloqueio e finalmente uma análise subjetiva do conteúdo recebido é usada. O trabalho conclui com a proposta de um Codificador de canal adaptável para Transport Stream.

## Palavras-chave

Códigos fontanais; Real-Time Transport Protocol (RTP); User Datagram Protocol (UDP); Códigos Reed-Solomon; MPEG-2 Transport Streams.

# Contents

I	Introduction	<b>15</b>
II	Transport Stream Monitoring	<b>19</b>
II.1	Transport Stream Structure	20
II.2	Transport Stream Synchronization	24
	<i>Rate calculation at the decoder</i>	25
	<i>Transport Stream Measurements</i>	26
III	IP Channel	<b>29</b>
III.1	IP as a Packet Erasure Channel	29
III.2	Overcoming Packet Drops and Jitter	31
	<i>Automatic Repeat Request (ARQ)</i>	32
	<i>Channel Coding for Video over IP</i>	33
IV	Simulation Scenarios	<b>37</b>
IV.1	Fountain Encoder Simulation	38
	<i>Input file and TS Selection Block (<math>TS_{SEL}</math>)</i>	39
	<i>Input Buffer (<math>B_{LTin}</math>)</i>	40
	<i>LT Encoder block (<math>E_{LT}</math>)</i>	40
	User defined parameters	40
	<i>Encoder's Output buffer (<math>B_{LTout}</math>)</i>	41
	<i>Interleaving (<math>I_{LT}</math>) and UDP packing (<math>UDP_{pack}</math>)</i>	42
	<i>IP Erasure Channel</i>	42
IV.2	Fountain decoder simulation	43
	<i>UDP Unpacking block</i>	44
	<i>LT decoder input buffer (<math>B_{DECin}</math>) and de-interleaver (<math>I_{LT}^{-1}</math>)</i>	44
	<i>LT Decoding</i>	45
	LT decoder implementation	45
	<i>LT decoder output buffer (<math>B_{LTDECout}</math>) and de-interleaving (<math>I_{LT}^{-1}</math>)</i>	46
IV.3	Repeating the Experiment with Reed-Solomon Codes: one-dimensional scheme	47
	<i>RS-1D encoder</i>	47
	<i>RS-1D decoder</i>	48
IV.4	Repeating the Experiment with Reed-Solomon Codes: two-dimensional case	49
	<i>RS-2D encoder</i>	49
	<i>RS-2D decoder</i>	52
V	Results	<b>55</b>
V.1	LT Code Performance	55
	<i>LT Code Performance: probability of unrecovered symbols</i>	55
	<i>Universality property</i>	56

V.2	Comparing the Performance of RS and LT codes	57
	<i>Random burst erasures</i>	58
	<i>Random single packet erasures</i>	58
	<i>Combination of Random single packet erasures and random burst erasures</i>	58
V.3	Visual impairments	59
V.4	Blocking Artifact Measure	61
VI	Conclusion	<b>67</b>
A	Fountain Codes	<b>69</b>
A.1	Main Properties	69
	<i>Rateless and Universality Properties</i>	69
	<i>Multicast scenario</i>	70
A.2	LT Encoding	71
A.3	LT Decoding	72
	<i>Degree Distribution Considerations</i>	72
B	Adaptive Channel Encoder	<b>75</b>
B.1	Simulation results and background	75
B.2	Overall workflow	76
	<i>Preliminary Transport Stream Analysis Block</i>	77
B.3	Results	79

## List of Figures

I.1	Typical IPTV architecture	17
II.1	Composition and packetizing of Transport Streams	21
II.2	Transport Stream structure	23
II.3	Transport Stream de-multiplexing	24
III.1	Binary Erasure Channel	30
III.2	Previous FEC scheme	34
III.3	Coding scheme defined in CoP 3.2	35
IV.1	LT Encoder	38
IV.2	Fountain Decoder Simulation	43
IV.3	Processing of G upon each iteration	46
IV.4	RS-1D Encoder	47
IV.5	RS-1D decoder	48
IV.6	RS-2D Encoder	49
IV.7	Two-Dimensional FEC	51
IV.8	Re-arrangement of data subjected to transmission	51
IV.9	RS-2D decoder	52
V.1	LT Code performance	56
V.2	Decode-ability Histogram for LT[8211,7896]	57
V.3	Decode-ability Histogram for LT[8370,7896]	57
V.4	Performance Comparison for random burst packet erasure	58
V.5	Performance Comparison for random single packet erasures	59
V.6	Performance Comparison for random burst and single packet erasures	59
V.7	Visual impairments for LT at $N \approx 0.8k$	60
V.8	Visual impairments for RS1D at $N \approx 0.8k$	60
V.9	Visual impairments for RS2D at $N \approx 0.8k$	61
V.10	Sample frame 'A' with high rate of discontinuity	63
V.11	Sum of discontinuities across all lines of frame 'A'	63
V.12	Sample frame 'B' with low rate of discontinuity	64
V.13	Sum of discontinuities across all lines of frame 'B'	64
V.14	BAI measurements	65
A.1	Robust Soliton Distribution	73
B.1	Adaptive LT encoder considering PSI and PCR	76
B.2	Sample frame of "flat" LT at $N = 1.075k$	79
B.3	Sample frame of "Adaptive" LT at $N$ slightly larger than $1.075k$	80