TURBO CODE APPLICATIONS

Turbo Code Applications

A Journey from a Paper to Realization

Edited by

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To all scientists who have dedicated
their efforts to the growth of communication
engineering and information theory societies

Preface

Turbo Code Applications: *a journey from a paper to realization* presents contemporary applications of turbo codes in thirteen technical chapters. Each chapter focuses on a particular communication technology utilizing turbo codes, and they are written by experts who have been working in related areas from around the world. This book is published to celebrate the 10^{th} year anniversary of turbo codes invention by *Claude Berrou Alain Glavieux and Punya Thitimajshima* (1993-2003). As known for more than a decade, turbo code is the astonishing error control coding scheme which its performance closes to the *Shannon's* limit. It has been honored consequently as one of the seventeen great innovations during the first fifty years of information theory foundation. With the amazing performance compared to that of other existing codes, turbo codes have been adopted into many communication systems and incorporated with various modern industrial standards. Numerous research works have been reported from universities and advance companies worldwide. Evidently, it has successfully revolutionized the digital communications.

Turbo code and its successors have been applied in most communications starting from the ground or terrestrial systems of data storage, ADSL modem, and fiber optic communications. Subsequently, it moves up to the air channel applications by employing to wireless communication systems, and then flies up to the space by using in digital video broadcasting and satellite communications. Undoubtedly, with the excellent error correction potential, it has been selected to support data transmission in space exploring system as well.

To emphasize on its applications, the effort for editing this book is not only to focus on the technical aspect of turbo code, but also to depict its impacts and up-to-date research works. This book aims to place in courses for graduate students, to involve in research for professional scientists and engineers, and to be a reference book. These interests lie in the field of digital communications, coding theory and information technology. Principle of turbo codes can be found widely in many text books and other online materials. Thus, this book intends to provide an advance coverage of turbo code applications for readers with background experience in this topic, and targets to review up-to-date applications of turbo code and its successors. With the best effort of well-known authors in related fields including the strong support of technical committee, readers are expected of having a technical book that obtains contemporary fruitful results of turbo codes.

Acknowledgments

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Keattisak Sripimanwat
February 2005

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List of Acronyms

3GPP	3rd Generation Partnership Project
4-PSK	Quaternary Phase Shift Keying
8PSK	8-ary Phase Shift Keying
ADSL	Asymemtric Digital Subscriber Line
AGC	Automatic Gain Control
APP	*a posteriori* probability
APSK	Amplitude Phase Shift Keying
ARQ	Automatic Repeat Request
ASIC	Application Specific Integrated Circuit
ASIP	Application Specific Instruction set Processor
ASK	Amplitude Shift Keying
ASM	Attached Sync Marker
ATM	Asynchronous Transfer Mode
AWGN	Additive White Gaussian Noise
BCC	Binary Convolutional Codes
BCCC	Binary Concatenated Convolutional Codes
BCH	Bose-Chaudhuri-Hocquenghem code
BCJR	Bahl, Cocke, Jelinek, and Raviv Algorithm
BER	Bit Error Rate
BICM	Bit-Interleaved Coded Modulation
bps	bit per second
BPSK	Binary Phase Shift Keying
BSC	Binary Symmetric Channel
BTC	Block Turbo Code
BWA	Broadband Wireless Access
CCSDS	Consultative Committee for Space Data Systems
CD	Compact Disc
CDMA	Code Division Multiple Access
CD-R	Read-only CD
CD-ROM	Read-only Memory CD

CD-RW	Rewritable CD
CGA	Chase-GMD Algorithm
CIRS	Cross-Interleaved Reed-Solomon codes
CMOS	Complementary Metal Oxide Semiconductor
CNES	Centre National d'Etudes Spatiales
CPM	Continuous-Phase Modulation
CRC	Cyclic Redundancy Check
CRSC	Circular Recursive Systematic Convolutional
CSI	Channel State Information
CTC	Convolutional Turbo Code
DFE	Decision Feedback Equalizer
DFG	Data Flow Graph
DLR	Deutschen Zentrum für Luft- und Raumfahrt
DMC	Discrete Memoryless Channel
DMS	Discrete Markov Source
DMT	Discrete Multi-Tone
DOW	Direct Overwrite
DSB-SC	Double Side-Band Suppressed Carrier
DSL	Digital Subscriber Line
DSP	Digital Signal Processing
DVB	Digital Video Broadcasting
DVB-RCS	Digital Video Broadcasting-Return Channel via Satellite
DVB-S	Digital Video Broadcasting-Satellite
DVB-S2	Digital Video Broadcasting-Satellite (second generation)
DVD	Digital Video Disc
DVD-R	Read-only DVD
DVD-RW	Rewritable DVD
EFM	Eight-to-Fourteen Modulation
eIRA	extended Irregular Repeat Accumulate (code)
EM	Expectation-Maximization algorithm
ESA	European Space Agency
ETSI	European Telecommunications Standards Institute
EXIT	Extrinsic Information Transfer
FER	Frame Error Rate
FIR	Finite Impulse Response
FPGA	Field Programmable Gate-Array
FSE	Fractionally-Spaced Equalizer
FSM	Finite State Machine
FWHM	Full Width at Half Maximum density
GF	Galois Field
GMD	Generalized Minimum Distance
GMSK	Gaussian Minimum Shift Keying
GPR	Generalized Partial Response
HCCC	Hybrid Concatenated Convolutional Code
HD-DVD	High-Density DVD

HDL	Hardware Description Language
i.i.d.	Independent and Identically Distributed
IIR	Infinite Impulse Response
ISI	Inter Symbol Interference
JAXA	Japan Aerospace Exploration Agency
LAN	Local Area Network
LBC	Linear Block Code
LDPC	Low Density Parity Check code
LLR	Log-Likelihood Ratio
LMMSE	Linear Minimum Mean-Square-Error
MAC	Medium Access Control
MAN	Metropolitan Area Network
MAP	Maximum *a posteriori* Probability
MIMO	Multiple-Input Multiple-Output
MLC	Multilevel Coded modulation
MLSD	Maximum Likelihood Sequence Detector
MMF	Multimode Fiber
MMSE	Minimum-Mean Square Error
MO	Magneto-Optical
MPEG	Moving Picture Experts Group
M-PSK	M-ary Phase Shift Keying
MTF	Modulation Transfer Function
NASA	National Aeronautics and Space Administration
NPML	Noise-Predictive Maximum-Likelihood
NRC	Non Recursive Convolutional
NRZ	Nonreturn-to-Zero
NRZI	Non-Return-to-Zero-Inverted
OFDM	Orthogonal Frequency Division Multiplexing
PAM	Pulse Amplitude Modulation
PC	Phase Change
PCC	Parallel Concatenated Code
PCCC	Parallel Concatenated Convolutional Code
PCE	Parallel Concatenated Encoder
PR	Partial Response
PRML	Partial Response Maximum Likelihood
PWM	Pulse-Width Modulation
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RCPCC	Rate-Compatible Punctured Convolutional Code
RCST	Return Channel Satellite Terminal
RIBB	Ring Interleaver Bottleneck Breaker
RLL	Runlength-Limited
RM	Reed-Muller Code
RS	Reed-Solomon Code

RSC	Recursive Systematic Convolutional
RSPC	Reed-Solomon Product Codes
SCC	Serial Concatenated Code
SCCC	Serial Concatenation Convolutional Code
SCE	Serial Concatenated Encoder
SCTC	Serially-Concatenated Turbo Codes
SCTCM	Serial Concatenated Trellis Coded Modulation
SDR	Sigma-to-Dynamic Ratio
SER	Symbol Error Rate
SIC	Soft Interference Cancellation
SIHO	Soft-Input / Hard-Output
SIMO	Single-Input Multiple-Output
SISO	Soft-Input / Soft-Output
SMF	Single-Mode Fiber
SNR	Signal to Noise Ratio
SOVA	Soft Output Viterbi Algorithm
SPB	Sphere Packing Bound
SSPA	Solid State Power Amplifier
ST	Space-Time
ST-BICM	Space-Time Bit-Interleaved Coded Modulation
STTrCs	Space-Time Trellis Codes
ST-TTCM	Space-Time Turbo Trellis Coded Modulation
TCC	Turbo Convolutional Code
TCM	Trellis Coded Modulation
TPC	Turbo Product Code
TTCM	Turbo Trellis Coded Modulation
UEP	Unequal Error Protection
UMTS	Universal Mobile Telecommunication Service
VA	Viterbi Algorithm
VLSI	Very Large Scale Integrated circuits
VSAT	Very Small Aperture Terminal
WEF	Weight Enumerating Function
WER	Word Error Rate
WGN	White Gaussian Noise
WSSUS	Wide Sense Stationary random processes with Uncorrelated Scattering
ZF-LE	Zero-Forcing Linear Equalizer

Chapter 1

Book Introduction

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"The invention of turbo codes did not result from a linear limit mathematical demonstration. It was the outcome of an empirical construction of a global coding/decoding scheme, using existing bricks that had never been put together in this way before." [1]

Claude Berrou (2001)

Getting a method to control or to mitigate error for data transmission or storage in digital communication systems, error control coding is one of the main communication techniques for this purpose. Obviously for more than fifty years, in advanced communication systems error control coding has played a very important role. It has been developing and adopted successfully into many application platforms.

Briefly regarding the historical timeline of error correcting codes, it was officially started in the year 1948 with the introduction of an information theory by *Claude E. Shannon.* A prediction of *Shannon* is that arbitrarily reliable communications are achievable by redundant channel coding. Subsequently, there were many pioneer works or milestones after Shannon's discovery. Starting in early 1950s, most researches emphasized on theoretical side or on the foundation of concerned mathematics [2]. Next, greater effort on searching for good codes structure was done during 1960s. Through the 1970s, the design of families of codes with larger code lengths and better performance was focused as the main target. Then, the transformation from theoretical era to the practice was concentrated in 1980s. It is noted that new design of encoders and decoders were presented frequently to digital communication engineering community during this period of time.

In that past fifty years, intensive research efforts have been done worldwide in order to achieve coding solution for solving related communication problems. Those are, among other things, 1) to have the better coding gain, 2) to reduce decoding complexity, and 3) to support or to associate working

K. Sripmanwat (ed.), Turbo Code Applications: a journey from a paper to realization, 1–14.

with other communication techniques. As the coding target, performance of the systems has been sailing closing to that *Shannon's* limit gradually. Resulting to recognized milestones along the past five decades, development of that error control coding came up many successful results. For examples, they are block codes, Hamming codes, Convolutional codes and Viterbi algorithm, Bose and Chaudhuri and Hocquenghem codes (BCH), Reed-Solomon codes (RS), and Trellis Coded Modulation (TCM). The historical breakthrough of turbo codes then arrived at early of 1990s.

In the year 1993, an annual international conference on communications or ICC was organized in Geneva, Switzerland. In that technical event, it was recognized that a paper of *Claude Berrou Alain Glavieux* and *Punya Thitimajshima* introduced an invention of new error control coding scheme. This novel method provides virtually error-free communications or obtains much better coding gain beyond that of any other existing codes. Gradually, it became a forefront of communication research and also inspires to generate other new numerous ideas until date. Turbo codes, on the same hand, plays an important role in most modern communication systems. It stepped out from that paper and successfully entered for the commercialization in the present telecommunication market. Undoubtedly from those accomplishments, a number of awards were then honored to its inventors [3]. As known for more than ten years, the first appearance of turbo codes to the public was on a paper entitled *"Near Shannon limit error-correcting coding and decoding: turbo-codes"* [4].

In this first chapter, it is an introduction of this great coding invention with related stories to the motivation and the organization of this book. That would give readers with more basic point of view before going on to its application in the following chapters. This book emphasizes mainly on advanced turbo codes applications. For more information, readers can find more details for the concept of error control coding and the principle of turbo codes from a number of other good sources. The helpful materials are available both online and in hardcopy styles. Some suggested books are as in [2, 5–7].

To follow by Sec. 1.1, it engulfs a brief turbo codes history. That provides the explanation to its evolutions and milestones, main related publications, patents, and awards. Sec. 1.2 guides readers to the organization of the book which emphasizes on the utilization. It summarizes all further thirteen chapters which present the grasp of turbo codes applications, and were written by leading scientists in the related communication areas.

1.1 A Brief History of Turbo Codes

"At first, it was a great surprise to observe that the bit error rate (BER) of these reconstructed symbols after decoding was lower than that of decoded information d. We were unable to find any explanation for this strange behavior in the literature." [8]

Claude Berrou and Alain Glavieux (1998)

This section is giving readers with a collection of important materials along the turbo codes discovery. That begins with a group of scientists which their work based on the contemporary scheme of convolutional encoding and Viterbi algorithm decoding. The main events are also depicted in the timeline of Fig. 1.1. Its details are presented as follows.

1.1.1 Evolutions and Milestones

Refer in the "Reflections on the Prize Paper: Near optimum error-correcting coding and decoding: turbo codes" published on June 1998 in IEEE information theory society newsletter [8], *Claude Berrou, Alain Glavieux,* and *Patrick Adde* were mentioned as key persons prior to the time of turbo codes invention. At the Ecole Nationale Supérieure des Télécommunications de Bretagne of France, these scientists started their work focusing on the *Soft-Output Viterbi Algorithm (SOVA).* It was based on the literature of *G. Battail* in 1987 [9] and of *J. Hagenauer* and *P. Hoeher* in 1989 [10]. Those were certainly referred to famous papers of *A.J. Viterbi,* "Convolutional codes and their performance in communication systems" [11], and of *G.D. Forney,* "The Viterbi algorithm" [12]. Initially, their research was to transfer the SOVA algorithm into hardware platform on MOS transistors in the simplest possible way as the target.

Consequently, they observed that SOVA can be considered as a signal-to-noise (SNR) amplifier. This could be mentioned as the beginning of "turbo"-codes concept because it stimulated them to consider "feed back" techniques that commonly used with electronic amplifier circuits. To explore that concept, they cascaded that signal-to-noise (SNR) amplifier or their SOVA version in order to obtain large asymptotic gains. This connection bases on "concatenation" coding technique of the well known concept in the literature. Their experiments were done on a serial concatenation of two ordinary convolutional codes at the early step. It was later concentrated on parallel concatenation. Because the idea of two component decoders working with the same clock signal matches with that the reason of hardware implementation (in parallel) for clock signal distribution. This parallel concatenation with amplifiers was considered to be meaningful only if the code is systematic, and it was a straightforward to use recursive systematic convolutional (RSC) codes at the final.

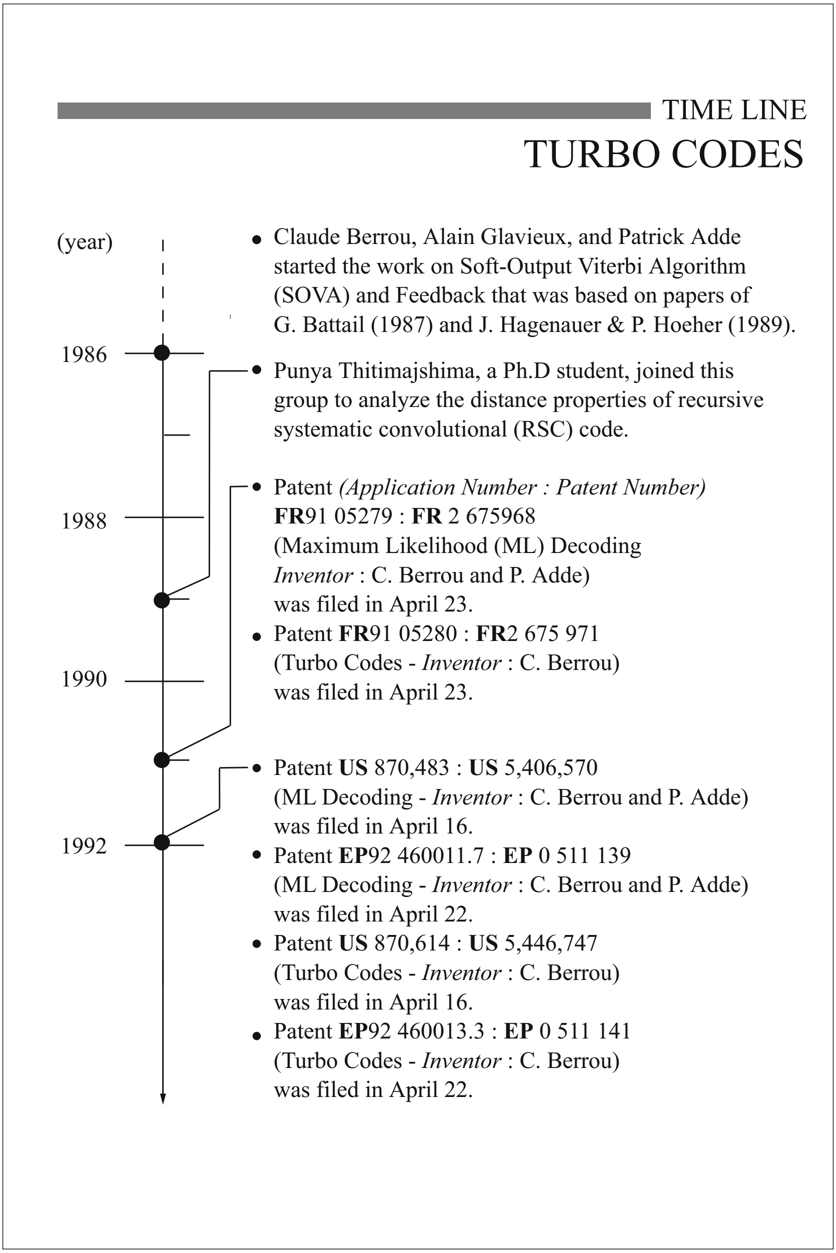

Fig. 1.1. Milestones of Turbo Codes.

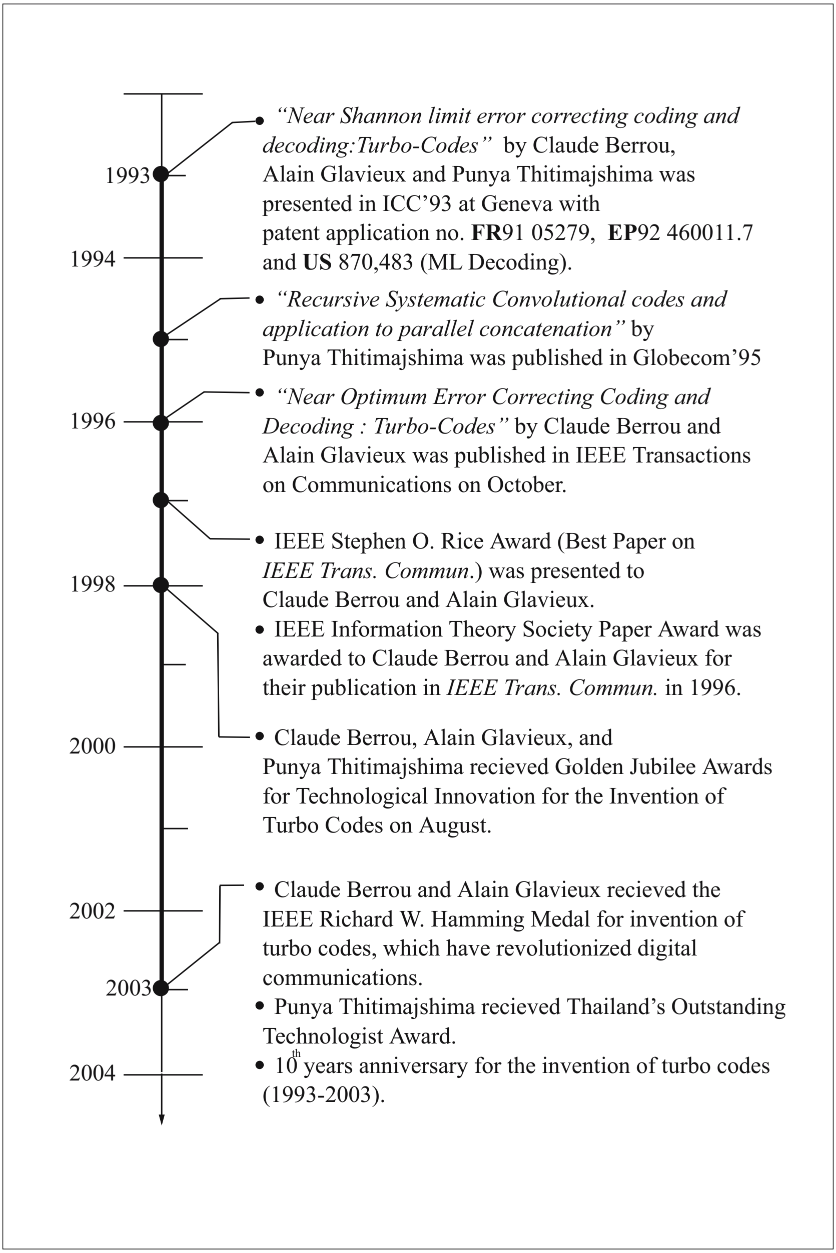

Fig. 1.1. Milestones of Turbo Codes (continued).

During this time of turbo codes foundation, a Ph.D student, *Punya Thitimajshima,* started joining this group to work on the distance properties analysis in the year 1989. His dissertation devotes to studying distance properties and of error probability of the recursive punctured systematic convolutional (RPSC) codes and their concatenation in serial and parallel styles. Certainly, it is combined with iterative decoding [13]. This work entitled *"Les codes Covolutifs Rcursifs Systmatiques et leur application la concatenation parallel",* as a dissertation at l'Universit de Bretagne Occidentale (UBO).

Gradually, the construction of original turbo codes was formed with related technical bricks. In order to solve obstruction in those initial works which reported on weighting problems, the beginning of SOVA was then replaced by Bahl-Cocke-Jelinek-Raviv (BCJR) algorithm [14] at the end of the discovery. It was mentioned that the first experiment with this novel coding construction was run in 1991 [15]. With the founding of following well known technical terms of extrinsic information, iterative decoding, recursive systematic convolutional codes, parallel concatenation, and non-regular interleaving, turbo codes was born finally.

There are two other main publications regarding turbo codes which appeared to the public after its introduction. First, a part of above dissertation was published in "Recursive Systematic Convolutional codes and application to parallel concatenation", which was presented at IEEE Globecom 1995 conference by *Thitimajshima* [16]. Moreover, at a year later another well known article was published as "Near optimum error correcting coding and decoding: turbo-codes" on the IEEE transactions on communications. That was issued on October 1996 and written by *Claude Berrou* and *Alain Glavieux* [17].

Since 1993, the legacy of turbo codes has opened new technical research areas continuously. It sparks new numerous ideas to improve its own performance. Moreover, its concept is combined with other communication techniques in order to improve overall system performance. Those examples of "turbo codes effect" are;

- *Turbo product codes / Turbo block codes* - a new iterative decoding algorithm for product (block) codes based on soft decoding and soft decision output of the component codes. It was invented as a new generation coding scheme with a high code rate.
- *Turbo equalization* - an iterative equalization technique that achieves highly impressive performance for communication through intersymbol interference (ISI) channels. That is for the multi-path propagation environment of wireless communications, or for other bandlimited-channel systems.
- *Turbo codes for multilevel or turbo trellis coded modulation (TTCM)* - the combined technique of turbo coding with high spectral efficiency modulation or non-binary (high) order signaling.

- *Space-time turbo codes* - the application of turbo codes with multiple transmit antennas for improving the data rate and/or the reliability of communications over fading channels for wireless communications.
- *Low-density parity-check codes (LDPC)* - a long time forgotten code that was invented much earlier in 1962. Turbo codes recall researchers to this date-back invention of LDPC codes. Then, to develop this complex coding scheme of the past to be a today competitive method for obtaining the better coding gain. This LDPC has returned to the society of communication engineering and has obtained the closer performance to that Shannon's limit. Obviously, LDPC was re-stimulated from the invention of turbo codes.

Moreover, turbo codes / turbo principle and their successors of above mentioned, have been applied successfully with other popular communication techniques. For examples, those are *multiuser detection, multiple-input multiple-output (MIMO)* - a technique that results to high spectral efficiency and capacity-approaching performance, and *orthogonal-frequency division multiplexing (OFDM)* - an efficient method capable of establishing high speed digital transmission through frequency selective fading channels. Details are presented in the upcoming chapters.

Finally, an obvious milestone of a young turbo code, has settled permanently along the road of digital communication development. Its successors, then, have been continuously following on the next miles and ahead.

1.1.2 Golden Patents and Awards

After the successful revolution in the year 1993, turbo code has been praised and crowned widely. Its impacts are not only in its technical communities but also found on economic, educational, and academic aspects. It affects to sparking of other technical ideas as mentioned before. Following its emergence, enhanced researchers worldwide generate a number of new related works. More than 400 patents involving its theory and applications have been filed afterward [18]. Successfully, it became one of the core technology for today's cutting edge communication products.

Prior to mentioning to the high valued patent of turbo codes, principle of the invention should be redefined with the construction concept comprising of a). Recursive Systematic Convolutional (RSC) coding and its parallel concatenation, b). iterative decoding, and c). extrinsic information.

Initially, it recalled us to the first glance of turbo code appearance in ICC'93, that was on the context with patent filing numbers of 91 05279 (France), 92 460011.7 (Europe), and 07/870,483 (USA) [4]. In fact, these numbers are entitled in French of *"Procédé de décodage d'un code convolutif à maximum de vraisemblance et pondération des décision, et décodeur correspondants"* for filing in France and Europe. *"Method for a maximum likelihood decoding of a convolutional code with decision weighting, and corresponding* *decoder"* is the coincided title that was filed in USA. They are all invented by *Claude Berrou* and *Patrick Adde* [19–21].

However, to follow above mentioned turbo coding concept, there are other numbers of concerned patents. The main or the golden patent should most match with that in the title of *"Procédé de codage correcteur d'erreurs à au moins deux codages convolutifs systématiques en parallèle, procédé de décodage itératif, module de décodage et décodeur correspondants"* or *"Error-correction coding method with at least two systematic convolutional coding in parallel, corresponding iterative decoding method, decoding module and decoder".* The first one was first filed in France (number 91 05280) on April 23, 1991. Later, this number was used as a priority data for filing other two main patents for expanding the right on turbo codes covering over Europe and USA. *Claude Berrou* is solely the inventor of them. Details are collected in Table 1.1.

Legally, the exclusive right on a patent exists for twenty years from the filing date. The patent owner may give permission to, or license, other parties to use the invention on mutually agreed terms. However, the patented invention may be available for commercial exploration by others in the countries which the patent is not filed. Thus, above mentioned turbo code patents which filed over three places (France, Europe, and USA), are then free to use at other places as in Asian countries.

The exclusive right on turbo codes and other turbo code related patents have been licensed and used for various application platforms. Many industrial standards have been incorporated. Consequently, a lot of product models from a number of chip making manufacturers have been placed in the market. In early of 2000s, the commercialization of this innovation focuses mainly for the new generation mobile and satellite communication systems. Licensing of those patents has been reported with impressive stories on its values [15, 22, 23].

Apparently, turbo code has revolutionized the communication engineering. Its successful stories and impacts have been highlighted. To guarantee those accomplishments, below awards and honors to its invention are the witness.

- In 1997, information theory society paper award was announced for *Claude Berrou* and *Alain Glavieux.* That was based on their work of *"Near optimum error-correcting coding and decoding: Turbo codes,"* published in IEEE transaction on communications–October 1996 [24]. In the same event, an honorable mention was given to *Punya Thitimajshima* for his contribution to the first turbo code paper in ICC'93.
- Based on the same work, *Claude Berrou* and *Alain Glavieux* were recipients of 1997 Stephen O. Rice award for the best paper in IEEE transactions on communications.
- Again, turbo code was honored in the year 1998 as one of the seventeen of great innovations. It was presented in the fifty year anniversary of information theory that *Claude Berrou, Alain Glavieux* and *Punya Thitimajshima* captured the IEEE information theory society's golden jubilee award for

Table 1.1. Basic Information of Golden Turbo Code Patent

Institut National de la Propriété Industrielle (INPI), France	
Title of invention : Proédé de codage correcteur d'erreurs à au moins deux codages convolutifs systématiques en parallèle, procédé de décodage itératif, module de décodage et décodeur correspondants	
Inventor	Claude Berrou
Assignee	France Telecom and Telediffusion de France S.A.
Application number	91 05280
Patent number	2675971
Filing date	April 23, 1991
European Patent Office(EPO), Europe	
Title of invention : Proédé de codage correcteur d'erreurs à au moins deux codages convolutifs systématiques en parallèle, procédé de décodage itératif, module de décodage et décodeur correspondants	
Inventor	Claude Berrou
Assignee	France Telecom and Telediffusion de France S.A.
Application number	92 460013.3
Patent number	0 511141
Filing date	April 22, 1992
United States Patent Office (USPTO), USA	
Title of invention : Error-Correction coding method with at least two systematic convolutional coding in parallel, corresponding iterative decoding method, decoding module and decoder	
Inventor	Claude Berrou
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technological innovation. This award was among other great inventions which were invented earlier during the past fifty years. For examples, those are algebraic decoding algorithm, convolutional codes, concatenated codes, Reed-Solomon (RS) codes, trellis coded modulation (TCM), and the Viterbi algorithm [3].

- In 2003, *Clude Berrou* and *Alain Glavieux* received IEEE Richard W. Hamming medal, for the invention of turbo codes, which have revolutionized digital communications. *Punya Thitimajshima* was honored with the 2003 Thailand's outstanding technologist award for turbo code invention.

All above impressive turbo code stories, from its invention through the related technological development as well as the achievements, motivates us to organize for this editorial book. Also, it is in order to celebrate another successful milestone for the first fifty years of the information theory that was founded by *Claude E. Shannon.*

1.2 Outline of Book: *a journey from a paper to realization*

> *"It's not often in the rarefied world of technological research that an esoteric paper is greeted with scoffing. Its even rarer that paper proves in the end to be truly revolutionary." [15]*
>
> *Erico Guizzo (2004)*

Starting with the application in data storage systems, first two chapters present with the application of turbo and turbo-like codes in the magnetic and optical storage media respectively. Typically, the demand for higher capacity, transfer rate, and storage density, is the main target of research in the field. In the hard-drive system, although the increasing of storage capacity is leading by the advances in head and media technologies, however coding and signal processing are those the cost-efficient methods to improve this storage capacity as well. In Chapter 2, the traditional media of magnetic recording channels where the application of recent developed error-control codes including turbo codes and low density parity check (LDPC) codes, is reviewed under the turbo equalization structure. It is remarked in this chapter that the iterative detection and decoding technique is the most potential candidate for the next generation read channels.

Another storage media follows in the Chapter 3. It presents the environment of read/write system of binary and multilevel (ML) for optical recording systems. In this chapter, it provides interesting principle of optical recording system through the mechanism of multilevel. Turbo product codes are applied potentially in this high-density storage system comparing with other conventional schemes. In addition, the concatenated coding for future optical recording systems is also discussed. It is noted with the necessity of using Reed-Solomon (RS) code as the outer part, and with iterative decoding nature codes as the inner one.

For wire or land line communication systems, applications of turbo codes are provided in two chapters. Those are for classical metal line and in fiber optic systems respectively. Chapter 4 presents turbo and turbo-like codes that is designed for Asymmetric Digital Subscriber Line (ADSL) which allows household consumers to access high speed broadband internet. In ADSL channel, by employing turbo and turbo-like coding it is possible to operate DSL links with greater robustness and reliability under the imperfect channel conditions. This chapter illustrates the approach to improve transmission performance by incorporating turbo and LDPC coding into ADSL technologies. The results of those applications are provided and compared with that of the concatenated coding scheme in ANSI standard (T1.413 or Wei code).

To reduce the negative effect from various types of noise and dispersion in fiber optic communications, error control coding by using turbo codes is one of the solutions. Chapter 5 reviews the application of turbo product codes (TPC) in optical fiber networks for both long-haul applications using single-mode fibers, and for short-haul multimode fiber links. Well organized sections and a thorough review would give readers with a complete guide to understand the basic of using contemporary error control codes in this type of channel.

For the present popular wireless communication systems, the application of turbo code principle is reviewed in five chapters. In order to improve overall performance in the wireless environment, they combine the turbo or iterative principle with other techniques. Those are, for examples, the multiple-input multiple-output (MIMO), space time coding, and orthogonal-frequency division multiplexing (OFDM).

In Chapter 6, the fascination of iterative demodulation and decoding for large constellation channel is presented. Code-Division Multiple Access (CDMA) and the multiple antenna technique are illustrated as that type of channel. Incorporating with turbo decoding principle, it is shown as the extremely useful scheme. Moreover, iterative demodulation and decoding is considered as a very powerful methodology to work with large numbers of interfering signals, and as the undergoing significant research.

Chapter 7 discusses importance of the application of the iterative decoding principle to the demodulation and error control decoding operations within a coded MIMO OFDM system. The principle of turbo decoding, that of iterative exchange of extrinsic information, is extended to this system and its receiver architecture. These techniques result high spectral efficiency and capacity-approaching performance in wireless channels.

Chapter 8 introduces a new paradigm for MIMO signal transmission by summarizing single and multiple antenna turbo coded modulation for using in the future wireless communication systems. This chapter presents the combining application techniques of space-time coding, turbo coding, and high order modulation scheme as the space-time turbo coded modulation (ST-TTCM). In the same hand, it is an application of turbo codes to design space-time trellis codes.

Currently, wireless communication industries have shown considerable interest in the progress of development of MIMO products which is used to support for high speed wireless communication systems. MIMO is advocated to be used in the future wireless data networks such as wireless local area network of IEEE 802.11 standards. It also will likely to be included in the next phase of the third generation (3G) mobile communication standardization. Chapter 9 reviews the turbo or iterative techniques with the above mentioned MIMO (turbo-MIMO systems). Its concentration is on the trade-off between performance and complexity for different detection schemes. Specifically, it in-