# From the authors

The seminal work "Threshold decoding" by J.L. Massey (1963) marked a new stage in the development of error-correction coding technology. A clear description of very simple methods with wholly satisfactory characteristics cemented their place in various communication systems at that time.

The subsequent emergence of the Viterbi algorithm in 1967 took coding techniques to a whole new level in terms of communication quality, enabling much more efficient encoding, since the proposed algorithm achieved optimum decoding for short codes in Gaussian channels. This prompted a large number of experts in coding theory and techniques to address the problem of improving coding efficiency, spurred on by the conviction that the rapid development of digital technologies would make it very easy to create concatenated and other more complex coding schemes. In this context, the issue of ensuring that decoders are kept simple to implement remained on the backburner for a long time, although the need for simpler decoding has never been completely off the agenda.

While publications on the effectiveness of threshold algorithms did continue to come out in the 1970s, the prevailing expert opinion on the possibilities of majority decoding schemes was highly conservative. There were many reasons for this. The most serious argument was the existence of the error-propagation (EP) effect, which from the outset severely reduced the already low efficiency of threshold procedures on account of the resulting strong error clustering at the decoder output. Unfortunately, no effective methods of reducing EP had been found. Nor did efforts to find special codes for majority procedures yield any better results than already known.

During the same decade, real results that were useful to some extent for threshold decoding practice were obtained by many experts in re-decoding experiments, particularly for binary convolutional codes. They demonstrated a small additional reduction in final decoding error probability in channels with a relatively low noise level. Yet all of these reports did not affect the – legitimate – overall view regarding the lack of effectiveness of the threshold decoder, particularly at a high noise level.

This book sets out the results of 40 years of research into majority type procedures which suggests that, under some fairly simple conditions and with some tweaking of threshold decoders, many codes can be decoded quite successfully, for a wide range of channel noise parameters. The results of application of these improved majority algorithms, called multithreshold decoders (MTD), turn out in many cases to be close to optimum, i.e. little different in terms of output error probability from the characteristics of exhaustive search algorithms. This has been shown by the authors of this book in various publications, both in theory and through simulation of the relevant procedures for special codes satisfying a set of very strict requirements. Decoders built in accordance with the principles described in this book have already been successfully implemented in many communication systems. In all cases of software and hardware implementation of the proposed multithreshold decoding methods, the authors and developers of communications systems have achieved the expected characteristics, which were sometimes completely unobtainable with other known error-correction algorithms with a reasonable degree of implementation complexity.

The main premises which made it possible in practice to raise the effectiveness of extremely simple threshold-type algorithms to the same level afforded by optimum exhaustive search processes come down to only two points, resolving the problem of fundamentally improving the quality of majority decoders.

First, majority algorithms can be extremely effective: there are very simple MTD algorithms that are capable of approaching the optimum decision at all decoding steps, for as long as the symbols being decoded continue to undergo changes at the threshold element.

Second, while the EP effect in threshold decoding very severely limits the capabilities of majority decoding procedures, this effect is quite manageable. Armed with a correct understanding and interpretation of it, we can formulate requirements and criteria that support the construction of codes with a very low level of EP at the corresponding decoder output and, ultimately, significantly improve the efficiency of iterative threshold procedures.

The property identified in the first premise is completely unexpected. Yet, after a small but fundamental modification of a conventional threshold decoder to convert it into a multithreshold decoder, the new decoder does indeed acquire the unique property of converging to the optimum exhaustive search decision, if some very simple conditions are met. It may legitimately be stated that no other currently known simple error-correction methods possess such properties.

The second premise deserves lengthy discussion and serious study, which are the subject of one of the chapters in this book. The successful solution of this complex problem has indeed made it possible to construct codes that are particularly effective when used in MTD.

The authors hope that, in this book, readers will to some extent find cogent answers to the many natural questions regarding the complexity, performance and technology of coding and multithreshold decoding. If interested, our readers will no doubt be able to continue the – potentially very promising for communication systems – study of MTD procedures, which have already found their place in many developments.

As will be shown below, the main task facing the researcher in devising new algorithms and corresponding codes is designing, simultaneously, a decoder and a code to be used in it, with a maximum degree of accuracy and optimization in respect of very many criteria. In other words, the simplicity of an MTD is achieved by dint of a more sophisticated and carefully organized design phase for both the code and its decoding algorithm. In this way, the problem of complexity of implementation of the algorithm is purposely transposed so that the technological challenges of creating a more effective decoder are solved by focusing on those components of complexity where improvement is the most accessible. For example, in most cases, to minimize the amount of computational effort required of an MTD, its volume of decoding operations with comparable efficiency is two or more decimal orders smaller than for the other algorithms, due to the significant amount of decoder memory using very long codes, which is quite acceptable - and sometimes even necessary - for high-speed communication systems. Many other important interrelationships between the code and decoder parameters will also be discussed below.

In concluding these introductory comments, the authors are firmly convinced that this first really comprehensive presentation of the optimization coding theory, notwithstanding of course certain shortcomings, will enable readers to find new ways of their own to further increase decoding efficiency using MTD-based processes as well. Their versatility, high degree of uniformity and extreme simplicity serve to substantially increase data transmission reliability in channels with low energy and at minimized cost for implementation of the core process of decoding.

The attentive reader may note that many of the features and capabilities of the algorithm presented are reviewed and commented repeatedly in the various sections of the book from different perspectives. The authors recognize the validity of this observation. This has been done in order to provide the most complete, comprehensive and at the same time clearest possible evidence and explanations of the properties and capabilities MTD. This approach to presentation of the material is dictated by the fact that, although all the key results were obtained by simple methods, many of them have not previously been used in the literature on coding theory and techniques, and are entirely new. Accordingly, the results, properties and characteristics of the algorithm, which are in many instances not so straightforward and sometimes even unexpected, have to be introduced gradually and painstakingly. We believe that the variety and form of presentation will help the reader to understand the results presented in the book, which may sometimes nevertheless take considerable effort and time to assimilate.

As a final note, it is worth emphasizing that all the research premises, theoretical results, ensuing practical implications and study findings presented are very simple. They rely solely on the most common concepts of coding theory and techniques, and do not require any knowledge of specialized domains of other related disciplines. The very fact that one needs no more than simple theoretical notions and common sense to gain an insight into the potential of these codes and multithreshold procedures means that students and professionals can be quickly versed in the new prospects for coding techniques based on the MTD algorithms. In turn, a good understanding of the capabilities of algorithms of this type will open the way in the future to raising and successfully solving new issues for the development of increasingly fast, cheap and simple MTD-type decoders for various communication systems.

The authors would like to thank the very many assistants, enthusiasts and highly skilled professionals who for many years have been helping them in their research and in applying the results obtained in specific systems and projects.

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For a visual representation of the effectiveness of multithreshold decoding, our readers are invited to view a small software animation demo (program designed for IBM-compatible PC with Windows), which illustrates some important features of MTD procedures for correcting errors in a channel with a high noise level. Hopefully, the psychological impact of this short “taster” demo will provide the necessary emotional and epistemological stimulus for fertile work with this book and with MTD going forward. Instructions on how to operate the demo program and the video itself can be accessed at **www.mtdbest.iki.rssi.ru** or at **www.mtdbest.ru**. These webpages also contain a wealth of different information on MTD algorithms.

A whole range of issues related to coding problems in general and the specific capabilities of MTD algorithms are also reviewed on our websites – in FAQ pages and in the extensive archive – from which one can gain a more accurate and graphical insight into the potential of MTD algorithms.

Three very useful laboratory works – also accessible on our webpages – may also be of significant assistance to our readers in the study of decoding methods based on MTD algorithms.

A few questions not discussed in this book have been analysed in our reference book "Error-correction coding. Methods and algorithms" (Помехоустойчивое кодирование. Методы и алгоритмы), published by the Hot Line – Telecom publishing house in Moscow (2004). Online stores, where you can buy both this book and the reference book, are easy to find at **www.findbook.ru**, or they can be purchased directly at **www.techbook.ru**.

A number of aspects of the theory of MTD algorithms were considered in the monograph by V.V. Zolotarev entitled "Multithreshold decoding theory and algorithms" (Теория и алгоритмы многопорогового декодирования), published by the Radio and Communications and Hot Line – Telecom publishing houses (2006), where some approaches to the application of MTD methods are explored in more detail.

Our new monograph “Multithreshold Decoders and Optimization Coding Theory” was published in 2012 by the Hot Line – Telecom publishing house in Moscow.

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