Book Review

Information Theory and Network Coding—Raymond W. Yeung (Springer, 2008). *Reviewed by I. Csiszár*

This is an updated and extended version of the author's 2002 book *A First Course in Information Theory*, reviewed in these TRANSACTIONS, vol. 49, p. 1969, July 2003.

The main new feature is an in-depth treatment of network coding. As stated in the Preface, network coding was still at its infancy in 2002, but since then it has developed into a research field of its own. The author could not say, but the reviewer can, that Raymond Yeung was one of the key contributors responsible for this development. One of the main goals of this book is to present the fundamental results about network coding in a unifying and coherent manner.

The book consists of two parts. Part I contains 16 chapters, 14 of them basically identical with those of the first version, not addressing networks. The two new chapters cover differential entropy and continuous alphabet (mainly Gaussian) channels. The second part is of main interest; it provides a comprehensive, state-of-the-art presentation of the theory of network coding. Much of the material is new compared with the 2002 book, and did not even exist in 2002; the rest has also been substantially updated.

About half of Part I is standard introductory material, suitable for a first course in information theory. The two new chapters, on differential entropy and Gaussian channels, have been added exactly in order to complete the coverage of the usual material of such courses. It should be mentioned that the treatment of discrete memoryless channels, both without and with feedback, has been considerably improved, making Chapter 7 decidedly superior to the original version (but an inconsistency in the definitions of channel capacity and rate–distortion function remains: the latter is operational, the former is not).

The remaining half of Part I deals with formal properties of information measures, including conditional independence relations, Shannon-type and non-Shannon-type inequalities. The main (unsolved) problem is to characterize the set Γ_n^* of all entropic vectors $\boldsymbol{h} = \{h_\alpha : \alpha \subset \{1, \ldots, n\}, \alpha \neq \emptyset\}$, i.e., those with $h_\alpha = H(X_\alpha)$ for some random variables $(X_1, \ldots, X_n)$, where $X_\alpha = (X_i : i \in \alpha)$. This is not commonly regarded as introductory material, part of it is rather complex, but it is certainly interesting, and this book is the best place where readers can find it. For mare details, see the review of the 2002 book.

Part II, consisting of 5 chapters, provides an up-to-date exposition of the fundamentals of network coding. This theory deals with the problem of "multicasting" (sending) data from one source to several receivers, or simultaneously multicasting data from several sources to specified sets of receivers. The available communication network is modeled by a directed graph whose edges are the communication links of known capacities. Unlike in classical communication networks, the role of the nodes is not restricted to routing the incoming messages, they may also encode them. Unlike in classical multiuser information theory, typically nonstochastic models are considered. When stochastic models are used, all sources and channels are assumed mutually independent, the channels most often are actually noiseless.

The treatment starts, in Chapter 17, with the celebrated example of the "butterfly network," showing that network coding may be superior to simple routing, and that several sources may be inherently more difficult to deal with than one source, since source separation need not be optimal. In the following three chapters, the case of one source is considered.

In Chapter 18, the basic max-flow bound is established for a general class of network codes.

Chapter 19 deals with linear coding for acyclic networks. For this case, the max-flow bound is reduced to a simple form involving the dimension of the code. Its achievability is proved, and much more. Several desirable properties of linear network codes are discussed, and are shown achievable when the base field is sufficiently large. Algorithms for constructing codes with such desirable properties are also provided.

In Chapter 20, the restriction to acyclic networks is dropped. Then codes in the previous chapter are inadequate, and they are replaced by convolutional linear codes; these and their decoding are studied in depth by algebraic techniques.

The last chapter is devoted to the much more difficult problem of multiple-source network coding. The main result is a (noncomputable) characterization of the achievable information rate region, while only inner and outer bounds were available in the 2002 book. This characterization involves (a variant of) the set Γ_n^* of all entropic vectors, thus computable inner (outer) bounds to the achievable rate region can be obtained by replacing this set by any computable inner (outer) bound. This strongly supports the author's conviction about the intrinsic relevance of the set Γ_n^*, and in particular, of non-Shannon-type information inequalities. It is also mentioned, without proof, that in the multiple-source case, linear network codes may not be optimal, and that each non-Shannon-type inequality is actually necessary for the characterization of the achievable rate region for some network coding problem.

The book is well written. A commendable new feature is that each chapter ends with a summary, short and clear. As before, each chapter is complemented with problems. I have found only a few typos. Unlike in the 2002 book, most reference numbers are correct, and the few errors of this kind were hardly avoidable.

In summary: This is a valuable book, its main strengths are the thorough and accessible treatment of network coding, and the in-depth presentation of the theory of entropic vectors. I believe many scientists will use it as a reference book. It can also be used as a textbook, and looks particularly suitable for special purpose courses. A course on network coding, even for students unfamiliar with information theory, can be ideally based on Part II of this book, relying upon Part I for information-theoretic prerequisites when needed.

Communicated by J. B. Anderson, Associate Editor for Book Reviews.
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