Book Review

Digital Communications Over Fading Channels—Marvin K. Simon and Mohamed-Slim Alouini (New York: Wiley, 2005, 2nd ed.). *Reviewed by Amer Hassan*

Channel modeling has been at the heart of cellular systems design in the past 25+ years. Understanding fading channel models enabled system designers and operators to optimize the commercial rollout of base stations and scale them to larger numbers of users. Interest in wireless systems is on the rise with recent allocations of spectrum. For instance, the unlicensed UNII band in the 5- and 60-GHz band are energizing new applications, ranging from local area network (LAN) networking to high-speed wireless HDMI. Similarly, the new allocations of licensed spectrum for WiMAX and Third/Fourth Generation systems across the globe promote new designs for mobile high-speed data. Digital communication design in new frequency bands first and foremost starts by evaluating the channel models. A channel model takes into consideration the frequency band and its propagation characteristics, and the different usage scenarios—whether it is indoors or outdoors, mobile or portable, and whether devices used have a high-gain antenna or a good low-noise amplifier, and so on. Almost all these channel models are characterized by one form or another of fading statistics, the exception arguably being satellite or fixed wireless broadband using high-gain antennas. Research on understanding fading is an ongoing effort. New allocations will likely dictate different modeling.

There are numerous books addressing details of the temporal and spatial (statistical) characteristics of fading; see [1]–[3] to name a few. Unlike these books, the book in review focuses on performance evaluation techniques for wireless systems in fading. The authors emphasize the moment generating function (MGF) approach as a unified method to evaluate the performance of wireless systems. In many cases, the book shows that closed-form expressions are possible in terms of the MGF.

The first part of the book introduces system performance measures, types of fading encountered by wireless systems, and the basic types of communication (coherent, partially coherent, and noncoherent). In particular, the following performance criteria are emphasized throughout the book: the usual average signal-to-noise ratio (SNR), outage probability (a good measure for multiuser networks), average bit error probability, amount of fading, and average outage duration. While the first three criteria are important and are commonly used, the last two are barely mentioned by other books. The amount of fade and especially the average outage duration has a direct impact on the upper networking layers, in particular the TCP layer, session layer, and sometimes the application layer. Thus, understanding these measures should provide a good insight into the performance and behavior of wireless networks. This is a fertile area for cross-layer research.

The types of fading presented in the book are quite comprehensive, from multipath characterized by Rayleigh (as assumed in cellular scenarios), to a combination of direct line of sight and multipath characterized by Rician (as assumed in most satellite systems or when a user is in direct line of sight to a cellular base station), to more complex fading models (such as Nakagami) and blockage (log-normal shadowing) models. This is sufficient to cover a wide area of wireless channel modeling. I have encountered one channel model for low orbit mobile satellite systems such as ICO, Iridium, or Globalstar that does not seem to have made it into the general literature; this model includes a direct line of sight and one more strong multipath plus diffuse scatters. I doubt its lack in the book will make a big difference.

The second part of the book focuses on mathematical tools that are useful in performance evaluation. It starts with alternative representations to the Gaussian Q-function and the Marcum Q-function, both of which are encountered in bit error probability calculations over additive white Gaussian noise (AWGN) channels. With fading included, the traditional approach involves complex integration. The alternative representations allow for closed-form expressions when averaged over fading statistics. The mathematical tools are then followed by useful expressions encountered in bit error probabilities and demonstrated by deriving the symbol-error-rate for multiple phase-shift keying (MPSK) modulation in fading channels. I would have liked to see [4] referenced for its derivation of an interesting expression used in evaluating bit error probability of MPSK modulation over N channel MRC reception. This part of the book ends with expressions for probability density functions for use in correlative fading, in particular, for Rayleigh, Nakagami, and log-normal channels.

A comprehensive and detailed performance evaluation for different receptions, several channel models, and the performance measures outlined earlier is addressed in the third part of the book. In particular, the elegance of the MGF approach is demonstrated for multichannel diversity receivers [maximum ratio combining (MRC), equal gain combining, selection combining, and switched diversity]. This coverage is the core of the book. In some cases, there are differences of expressions between the traditional approach and the MGF approach. Suboptimum receivers, where simple expressions for the MGF approach are not possible, are also addressed. The book particularly shows that for a broad variety of modulation/detection techniques and practical fading channels, there exists an MGF-approach that simplifies the evaluation of performance. In most of these instances, the MGF approach encompasses a unified framework that allows the development of a generic set of tools to replace case by case studies. In many cases, resulting expressions consist of a single integral with finite limits and an integrand composed of elementary functions. The book also covers the use of a partial MGF approach to circumvent a computationally complicated MGF expression with multidimensional integrals in the generalized selection combining case.

The first three parts described above are for single user, mostly flat fading, uncoded communication systems over a variety of fading models.

The fourth part is on uncoded multiuser communications. Outage probability is a very important criterion to assess the performance of cochannel interference limited, multiuser communication in fading channels. This part investigates outage probability for different fading statistics with cochannel interference and noise. This is followed by an evaluation of outage probability with outage assumed when signal power to total interference power (S/I) or signal power to thermal noise power (S/N) is less than the outage threshold. The results in this section take into account fading, but do not include the effects of shadowing, which can be done via further averaging. I found the coverage on optimum combining (OC) very interesting and deserving of special attention. In OC, the diversity combining is the one max-

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imizing signal power to total interference plus thermal noise power (SINR). It is known that such a technique provides better performance than MRC. This can manifest itself in increased channel capacity, for example. Maximizing SINR using adaptive antenna array techniques has been studied in the literature in pure AWGN and in slow fading. In this part of the book, the unifying MGF framework is again applied to evaluate the performance of OC, including effects such as the number of interferers as a function of antenna elements and channel correlation due to nonideal spatial separation. This part of the book concludes with a brief chapter on direct sequence code division multiple access (CDMA) in fading, both single carrier and multicarrier.

The fifth and last part of the book deals with coded digital communication in fading. However, the coverage is limited to MPSK with trellis-coded modulation. In particular, this part focuses on evaluating the pairwise error probability using the transfer function bound to arrive at a union bound. The two cases of perfect channel state information (CSI) and no CSI are included. Perfect interleaving is assumed throughout, resulting in decision statistics similar to those obtained with diversity combining in uncoded systems. Thus, the unified approach using MGFs is easily applied in coded memoryless channels. In comparison with the earlier parts, this part of the book lacks numerical results. It also does not provide a direct comparison with uncoded systems. However, I found the section on multichannel transmission simple and easy to follow. This is exemplified by the good overview of Alamouti's diversity technique. This part concludes by a simple and brief coverage of space-time coding basics, and capacity of fading channels.

I would compare this book to a numerical recipes book that is very useful as a reference, but not as a college textbook. The recipes in the book provide expressions, tools, and a rich set of performance numerical results, using the MGF approach when possible; the authors point out when this is not possible. The book also provides a rich set of references.

A few minor criticisms can be made. It would be good for the revised edition of the book to use bit error probability instead of symbol error rate, symbol error probability, etc. Also, one notation should be used for references. Some plots (e.g., pp. 790 and 791) have a caption and some do not. Also, I noticed the use of M as $E(X)$ rather than MGF (p. 596). Despite these criticisms, the book is a welcome and detailed addition to the communication theory literature.

REFERENCES

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