

DE GRUYTER  
OLDENBOURG

GRADUATE

*Nataša Živić*

# MODERN COMMUNICATIONS TECHNOLOGY



Nataša Živić

# **Modern Communications Technology**

---

**DE GRUYTER**  
OLDENBOURG

**Author**

Dr.-Ing. habil. Nataša Živić  
University of Siegen  
Chair for Data Communications Systems  
Hoelderlinstrasse 3, D-57068 Siegen  
Germany  
natasa.zivic@uni-siegen.de

ISBN 978-3-11-041337-3  
e-ISBN (PDF) 978-3-11-041338-0  
e-ISBN (EPUB) 978-3-11-042390-7

**Library of Congress Cataloging-in-Publication Data**

A CIP catalog record for this book has been applied for at the Library of Congress.

**Bibliographic information published by the Deutsche Nationalbibliothek**

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.dnb.de>.

© 2016 Walter de Gruyter GmbH, Berlin/Boston

cover image: agsandrew/iStock/thinkstock

Printing and binding: CPI books GmbH, Leck

♻️ Printed on acid-free paper

Printed in Germany

[www.degruyter.com](http://www.degruyter.com)

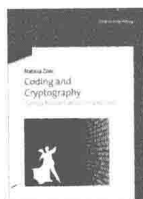


Nataša Živić

**Modern Communications Technology**

De Gruyter Graduate

## Also of Interest



### *Coding and Cryptography*

N. Živić, 2013

ISBN 978-3-486-75212-0, e-ISBN (PDF) 978-3-486-78126-7



### *Chaotic Secure Communication*

K. Sun, 2016

ISBN 978-3-11-042688-5, e-ISBN (PDF) 978-3-11-043406-4,  
e-ISBN (EPUB) 978-3-11-043326-5, Set-ISBN 978-3-11-043407-1



### *Computation and Communication Technologies*

S.T. Kumar, B. Mathivanan (Eds.), 2016

ISBN 978-3-11-045007-1, e-ISBN (PDF) 978-3-11-045010-1,  
Set-ISBN 978-3-11-045293-8



### *Communication and Power Engineering*

R. Rajesh, B. Mathivanan (Eds.), 2016

ISBN 978-3-11-046860-1, e-ISBN (PDF) 978-3-11-046960-8,  
Set-ISBN 978-3-11-046961-5

## Special Thanks

I would like to thank everybody involved in the writing, proofreading, material searching, consulting and publishing of this book.

In particular, I would like to express my special thanks to Professor Christoph Ruland for his general support.

I am much obligated to my esteemed colleague Obaid ur Rehman for his great help in preparing this manuscript, as well as my colleagues Iva Salom and Dejan Todorovic for their contribution about the audio signal in Chapter 2.

I express my appreciation to all my colleagues from the Institute for Data Communications Systems in Siegen for their colleague fairness and support. My special thanks go to Amir Tabatabaei as well as for consultancy with Robin Fay and preparing of some figures by Tao Wu.

I am very grateful to Professor Ljiljana Knezevic and her help in writing the book in English.

I would also like to express my gratitude to my family for their patience, support in everyday life and tolerance for the time involved in the book preparation.

At the end, I thank the publisher for his patience and professionalism during the time of the cooperation.

The author

Siegen, June 2016



# Foreword

This book is written using a decade-long experience in teaching “Fundamentals of Communications” and “Digital Communications Technology” at the University of Siegen, Germany. Thus, one part of the material is based on the scripts used for these lectures, as well as on the scripts for “Cryptographic methods and applications”. Another part of the presented material is based on the author’s working experience, which introduces a contribution to the book needed for engineering practice. Finally, several parts of the presented material are a result of work in the research field.

There are numerous books about communications technologies providing a basic knowledge for students and engineers. These books cover more or less the topics which cannot be substituted in learning communications technologies. Having that in mind, this book is written in a way that these essential topics are also present, but not with too many details which can be found in already existing literature. For example, topics on modulation, line coding and transmission channel are placed in one chapter, instead of three separate chapters, which is a common practice in most of literature. Similarly, information theory and source and channel coding are also merged into one chapter.

Instead, several topics which are not emphasized in most of the general books about communications technologies find more place and a greater emphasis in this book, as they are important for the state-of-the-art and possibly future development of communications. Therefore, one chapter is devoted only to the transmission over the wireless channel as wireless communications are dominating nowadays; another chapter is dedicated to wired transmission with accent to modern digital technologies and optical transmission, and a separate chapter addresses cryptography, which is inescapable in today’s communication systems.

It is never easy to find the optimal amount of content and to introduce the needed background of mathematics and physics necessary for understandable and sufficient explanation of different topics, terms and concepts. This task is even more difficult when the technology from the past has to be jointly explained with the modern one, especially considering the fast progress and merging of communications technologies. It is up to the reader to estimate how far the book succeeded in the trial to put the basic knowledge together with the modern trends.

The author

Siegen, June 2016





# Contents

<b>1</b>	<b>Signals and Systems — 1</b>
1.1	Communication System — 1
1.2	Data and Signals — 3
1.2.1	Representation of Signals — 7
1.2.2	Harmonic Analysis of Periodic Signals — 11
1.2.3	Harmonic Analysis of Aperiodic Signals — 20
1.2.4	Correlation and Convolution — 22
1.2.4.1	Correlation of Periodic Signals — 23
1.2.4.2	Convolution of Periodic Signals — 26
1.2.4.3	Correlation of Aperiodic Signals — 28
1.2.4.4	Convolution of Aperiodic Signals — 29
1.2.5	Bandwidth and Filtering — 31
1.3	Discretization — 32
1.4	Compressive Sensing — 36
1.4.1	Background — 36
1.4.2	Compressive Sensing Model — 39
1.4.3	Conditions for Signal (Sparse) Recovery in Compressive Sensing — 39
1.5	Discrete and Digital Signals — 41
1.5.1	Discrete Signals — 41
1.5.1.1	Finite Impulse Response — 43
1.5.1.2	Infinite Impulse Response — 44
1.5.2	Digital Signals — 46
1.6	Discrete and Fast Fourier Transform — 47
1.6.1	Discrete Fourier Transform (DFT) — 47
1.6.2	Spectrum Forming and Window Functions — 48
1.6.3	Fast Fourier Transform (FFT) — 51
<b>2</b>	<b>Typical Communications Signals — 57</b>
2.1	Speech — 57
2.1.1	Production and Modelling — 57
2.1.2	Speech Channel Bandwidth and Power of Speech Signal — 60
2.1.3	Current Values of Speech Signal — 63
2.1.4	Coding and Compression — 64
2.2	Audio — 69
2.2.1	Sound and Human Auditory System — 70
2.2.2	Audio Systems — 73
2.2.3	Digital Audio Systems — 76
2.2.3.1	Audio Coding — 77
2.2.4	Audio in transmission systems — 79

2.2.4.1	File Formats and Metadata — 79
2.2.4.2	Digital Broadcasting, Network and File Transfer — 80
2.3	Image — 81
2.3.1	Digital Image Processing System — 82
2.3.2	Digital Image Processing Operations and Methods — 83
2.3.2.1	Image Representation and Modelling — 84
2.3.2.2	Image Improvement — 84
2.3.2.3	Image Restoration — 86
2.3.2.4	Image Compression — 86
2.3.2.5	Image Analysis — 92
2.4	Television — 92
<b>3</b>	<b>Random Processes — 99</b>
3.1	Probability Theory — 99
3.1.1	Terms and axioms of the probability theory — 100
3.1.2	Conditional Probability, Total Probability and Bayes' Theorem — 102
3.2	Random signals — 104
3.2.1	Random Variables and Random Vectors — 105
3.2.1.1	Distribution Function and Probability Density Function — 106
3.2.1.2	Random Vectors — 107
3.2.1.3	Conditional Probabilities of Random Vectors — 108
3.2.2	Examples of Often Used Distributions — 109
3.2.2.1	Uniform Distribution — 109
3.2.2.2	Normal (Gaussian) Distribution Function — 110
3.2.2.3	Exponential Distribution Function — 111
3.2.3	Variance and Higher Order Moments — 113
3.2.4	Moment Generating Function — 116
3.2.5	Characteristic Function — 118
3.2.6	Distribution of Function of Random Variable — 119
3.2.7	Central Limit Theorem — 121
3.3	Stochastic Processes — 123
3.3.1	Ensemble, Stationarity and Ergodicity — 123
3.3.2	Power Spectral Density and Wiener-Khinchin Theorem — 126
3.3.2.1	White and Colored Noise — 128
<b>4</b>	<b>Information Theory and Coding — 129</b>
4.1	Information Theory — 129
4.1.1	Coding Components of Communication System — 129
4.1.2	Definition of Information — 131
4.1.3	Entropy — 132
4.2	Source Coding — 136

4.2.1	Code Definition —	138
4.2.2	Compression Algorithms —	140
4.2.2.1	Huffman Coding —	140
4.2.2.2	Arithmetic Coding —	142
4.3	Channel Coding —	144
4.3.1	Block Coding —	145
4.3.1.1	Hamming Codes —	147
4.3.1.2	Cyclic Codes —	148
4.3.1.3	Cyclic Redundancy Check Codes —	150
4.3.1.4	Reed Solomon Codes —	152
4.3.1.5	Low Density Parity Check Codes —	155
4.3.2	Convolutional Coding —	159
4.3.2.1	Viterbi Algorithm —	162
4.3.2.2	Turbo Codes —	163
4.4	Concatenated Codes —	171
4.5	Joint Source and Channel Coding —	172
<b>5</b>	<b>Digital Transmission —</b>	<b>175</b>
5.1	Model of a Digital Transmission System —	175
5.2	Channel Model —	175
5.3	Channel Capacity —	182
5.4	Base-band Transmission —	186
5.4.1	Line Coding —	186
5.4.1.1	Non-Return-To-Zero (NRZ) and Non-Return-To-Zero Inverted (NRZI) —	188
5.4.1.2	Return-To-Zero (RZ) and Return-To-Zero Inverted (RZI) —	189
5.4.1.3	Alternate Mark Inversion and Inverted Alternate Mark Inversion —	191
5.4.1.4	Manchester —	192
5.4.1.5	Differential Manchester —	192
5.4.1.6	High Density Bipolar n (HDBn) —	193
5.4.1.7	Binary 3 Ternary / Modified Monitored Sum 43 —	194
5.4.1.8	Scrambling —	195
5.4.2	Intersymbol Interference —	196
5.4.3	Partial Response Signalling —	203
5.4.4	Optimization of Transmission System —	204
5.4.4.1	Optimum and Matched Filter —	204
5.4.4.2	Correlation Receiver —	205
5.4.4.3	Integrate & Dump Receiver —	205
5.4.5	Equalization —	206
5.5	Digital Modulation —	207
5.5.1	Amplitude Shift Keying —	208

9.1.1	Crypto ABC — <b>361</b>
9.1.2	Cryptographic Design Principles — <b>362</b>
9.1.3	Encryption/Decryption — <b>362</b>
9.1.4	Key Based Encryption — <b>363</b>
9.1.5	Symmetric Cryptography — <b>364</b>
9.1.6	Asymmetric Cryptography — <b>365</b>
9.1.6.1	Asymmetric Encryption — <b>366</b>
9.1.6.2	Digital Signatures — <b>366</b>
9.1.6.3	Man-in-the-Middle Attack — <b>368</b>
9.1.6.4	Certificate — <b>368</b>
9.2	One Way Collision Resistant Hash Function — <b>370</b>
9.2.1	Characteristics — <b>370</b>
9.2.2	Security of a One Way Collision Resistant Hash Function — <b>371</b>
9.2.2.1	Random Oracle and Avalanche Effect — <b>373</b>
9.2.3	Hash Functions in Practice — <b>373</b>
9.3	Block Cipher — <b>374</b>
9.3.1	Product Cipher — <b>374</b>
9.3.2	Padding — <b>375</b>
9.3.3	Block Ciphers in Practice — <b>376</b>
9.3.3.1	Advanced Encryption Standard — <b>376</b>
9.3.3.2	Lightweight Cipher PRESENT — <b>377</b>
9.4	Modes of Operations for Block Ciphers — <b>379</b>
9.4.1	Electronic Codebook (EBC) — <b>379</b>
9.4.2	Cipher Block Chaining (CBC) — <b>381</b>
9.4.3	Cipher Feedback (CFB) — <b>382</b>
9.4.4	Output Feedback (OFB) — <b>383</b>
9.4.5	Counter Mode (CTR) — <b>384</b>
9.4.6	Other Modes of Operation — <b>385</b>
9.5	Bit Stream Ciphers — <b>386</b>
9.6	Message Authentication Codes — <b>388</b>
9.6.1	Generation — <b>388</b>
9.6.2	MAC generation using symmetric block cipher — <b>389</b>
9.6.3	MAC Generation Using Dedicated Hash Function — <b>390</b>
9.6.4	Security Aspects — <b>390</b>
9.6.4.1	Length Extension Attack — <b>390</b>
9.7	Digital Signatures — <b>392</b>
9.7.1	Digital Signatures with Appendix — <b>392</b>
9.7.2	Digital Signatures with Message Recovery — <b>394</b>
9.7.3	RSA — <b>395</b>
9.7.3.1	Introduction — <b>395</b>
9.7.3.2	Generation of RSA key system — <b>396</b>

9.7.4	El-Gamal —	<b>398</b>
9.7.4.1	Introduction —	<b>398</b>
9.7.4.2	Authentication of Message —	<b>398</b>
9.7.4.3	Verification of Message —	<b>399</b>
9.7.5	Digital Signature Algorithm (DSA) —	<b>400</b>
9.7.5.1	Introduction —	<b>400</b>
9.7.5.2	Authentication of Message —	<b>400</b>
9.7.5.3	Verification of Message —	<b>401</b>
9.7.6	Elliptic curve digital signature algorithm (ECDSA) —	<b>402</b>
9.7.6.1	Elliptic Curves —	<b>402</b>
9.7.6.2	ECDSA —	<b>405</b>
9.8	Random Numbers —	<b>407</b>
9.8.1	Randomness —	<b>407</b>
9.8.2	Random Number Generation —	<b>408</b>
9.8.2.1	True Random Number Generation —	<b>408</b>
9.8.2.2	Pseudo Random Number Generation —	<b>408</b>
9.8.2.3	Cryptographically Secure Pseudo Random Number Generation —	<b>409</b>

<b>References —</b>	<b>411</b>
---------------------	------------

<b>List of Acronyms —</b>	<b>431</b>
---------------------------	------------

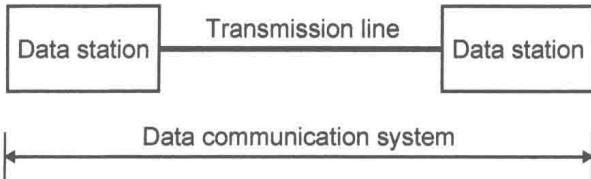
<b>Index —</b>	<b>447</b>
----------------	------------



# 1 Signals and Systems

## 1.1 Communication System

Signals are electrical equivalents of data to be transmitted through a communication system. A complete communication system consists of two stations, each equipped with a transmitter and a receiver, or combined into a single device called transceiver (Fig. 1.1). The medium of signal transmission can be wired (see Chapter 7) or wireless (see Chapter 8).



**Fig. 1.1:** Elements of communication system.

A data station consists of a Data Terminal Equipment (DTE) and a Data Circuit Terminating Equipment (DCE). DTE converts user data into signals or reconverts received signals into user data. DCE is intermediate equipment between DTE and a data transmission circuit (Fig. 1.2).

The boundary between DTE and DCE is called interface and is defined according to the properties of transmission lines and exchanged signals between DTE and DCE. Intermediate devices (e.g. error control device, synchronization devices etc.) can be added into interfaces. Generally, an interface is also a boundary for performance and achievement of a network provider, his ownership and responsibility. Interfaces are internationally standardized, e.g. by ITU-T:

- V: Data Communication over the telephone network (e.g. V.24/V.28, V.10, V.11)
- X: Data networks, open system communications and security (e.g. X.20, X.21, X.25, X.26, X.27)
- I: Integrated Services Digital Network (ISDN)
- G: Transmission systems in media, digital systems and networks
- H: Audiovisual and multimedia systems
- T: Terminals for telematic services
- Z: Languages and general software aspects for telecommunication systems
- etc.



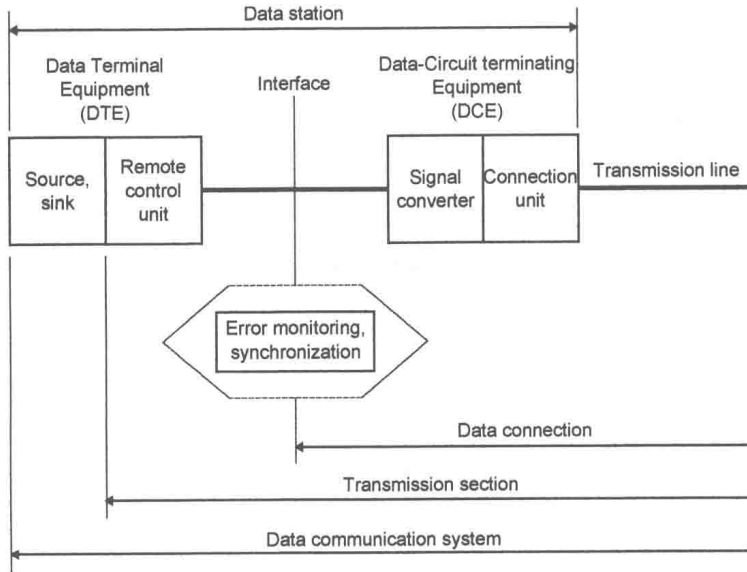


Fig. 1.2: Elements of data station.

A DTE is a functional unit serving as a data source or a data sink and providing control function for data communication accordingly to the link protocol. A DTE can be a user himself or a device interacting with user, e.g. through a human-machine interface. DTE consists of:

- Data source or data sink in a form of data producers (input devices), data processing devices and data consumers (output devices).
- Controller with data preparation device, parallel-serial converter and serial-parallel converter, error control device, address recognizer end device, synchronizer device, sending or receiving part, management and data transmission control.

Examples of DTEs are terminals, memories, keyboards, printers, data concentrators and computers.

A DCE (also called Data Communication Equipment and Data Carrier Equipment) performs functions such as: line clocking, conversion of signals from DTE in corresponding form for transmission (line coding and modulation, see Chapter 5) and, the opposite, conversion of transmitted signals into a form understandable for DTE (line decoding and demodulation, see Chapter 5). A DCE can be realized as:

- Modem (modulator/demodulator) for broadband transmission
- Data connection device for leased lines
- Data remote control device for data lines
- Network Terminator (NT) for ISDN and xDSL (see Chapter 7)