Theory and Design of Digital Communication Systems

Providing the underlying principles of digital communication and the design techniques of real-world systems, this textbook prepares senior undergraduate and graduate students for the engineering practices required in industry. Covering the core concepts, including link analysis, modulation, demodulation, spread spectrum, equalization, channel fading effects, and channel coding, it provides step-by-step mathematical derivations to aid understanding of background material. In addition to describing the basic theory, the principles of system and subsystem design are introduced, enabling students to visualize the intricate connections between subsystems and understand how each aspect of the design supports the overall goal of achieving reliable communications. Throughout the book, theories are linked to practical applications with over 250 real-world examples, whilst 370 varied homework problems in three levels of difficulty enhance and extend the text material. With this textbook, students can understand how digital communication systems operate in the real world, learn how to design subsystems, and evaluate end-to-end performance with ease and confidence.

Tri T. Ha is a Professor in the Department of Electrical and Computer Engineering at the Naval Postgraduate School (NPS), Monterey, California, a position he has held since 1989. Prior to joining NPS he worked at Fairchild Industries and GTE, and was an Associate Professor at Virginia Tech for four years. He is an IEEE Fellow who has written two previous textbooks, and his current research interests are in wireless communications and cyber warfare.

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TRI T. HA
Naval Postgraduate School, Monterey, California

CAMBRIDGE
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Shaftesbury Road, Cambridge CB2 8EA, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment,
a department of the University of Cambridge.

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www.cambridge.org
Information on this title: www.cambridge.org/9780521761741

First published 2011
Reprinte 2020

A catalogue record for this publication is available from the British Library

Library of Congress Cataloging-in-Publication data
Ha, Tri T., 1949–
Theory and design of digital communication systems / Tri T. Ha.
p. cm.
ISBN 978-0-521-76174-1 (hardback)
1. Digital communications. I. Title.
TK5103.7.H35 2011
384–dc22
2010024374

ISBN 978-0-521-76174-1 Hardback

Additional resources for this publication at www.cambridge.org/9780521761741

World peace must develop from inner peace. Peace is not the absence of violence. Peace is the manifestation of human compassion.

14th Dalai Lama of Tibet (Inscription on United States Congressional Medal)

Contents

Preface

This book was written with two goals in mind: to provide the underlying principles of digital communication and to study design techniques integrated with real world systems. The ultimate aim of a communication system is to provide reliable transmission of information to the user(s). This fundamental foundation was established in 1948 by Claude Shannon, the founding father of information theory, and led eventually to the development of modern digital communication. Analog communication is near extinction or at the very gate of it. The full spectrum dominance of digital communication has arrived and new frontiers are being established every decade; from cellular systems to wireless LAN and MAN, the bit rates are being pushed ever higher for ubiquitous mobile applications.

Knowing the limit of digital transmission is vital to the design of future communication systems, particularly mobile wireless systems, where both spectrum and power are precious resources, and design techniques can be used to manipulate these two main resources to fit real world applications. No single technique can cover all the requirements of a modern communication system, which makes it necessary for students to understand the intricate web between subsystems, each designed to support others to achieve the common goal of reliable communication.

The book contains more than 250 examples to help students achieve a firmer understanding of the subject. The problems at the end of each chapter follow closely the order of the sections. They are designed for three levels: level one covers the straightforward application of equations; level two requires patience and deep thinking; whilst level three requires some research of the literature to assist in finding a solution. A solutions manual for the instructor accompanies the book.

The book was written for both senior undergraduate and graduate students studying communications at universities and colleges. The entire book is suitable for two-semester courses in digital communications. The first course is typically a one-semester senior course in digital communication, which may be taken by students new to studying communications (the conventional wisdom is that students should learn analog communication before learning digital communications) or after completing an introductory course in communication systems (one that is heavy in analog communication systems such as AM and FM). The second course is a one-semester course for graduate students who already have a firm background in random variables and processes. The practical material included in this book (much of it focused on commercial and military systems) will be helpful for practitioners and professionals in the digital communication field.

As in the learning of any subject, some prerequisites are required for the reading of this book. A first course in probability theory is necessary and exposures to random processes would be helpful. Readers should also be familiar with linear system analysis. A knowledge of analog communication is helpful but not required. For readers who do not have the patience to go through all the design techniques but would appreciate the beauty of the underlying principles, we recommend our favorite book, *Principles of Digital Communication*, authored by the legendary Robert G. Gallager.

Acknowledgements

I would like to express my thanks to Dr. Phil Meyler of Cambridge University Press for his enthusiastic support and for suggesting the title of the book to closely reflect its coverage. I would like to thank the anonymous reviewers for their valuable comments that helped in improving the book. I am grateful for the support of my friends Nathan Beltz, Professor Vicente Garcia, Professor Jeff Knorr, Professor Frank Kragh, Donna Miller, Rita Painter, Professor Clark Robertson, Professor Wei Su, Dr. Jan Tighe, and Dr. Charlie Victory. I also would like to thank my students over the years for their valuable suggestions to improve the original notes. I am grateful to my parents for providing me the opportunity to go to the United States for higher education, and to Thuy, Khanh, Tuan, Huong and Dennis, Thu, and Hien for their help and support over the years. This book is dedicated to the people who work tirelessly for world peace.

Symbols

A	amplitude, smallest signal amplitude in MQAM, azimuth angle
$\mathbf{A}$	matrix $\mathbf{A}$
$\|\|\mathbf{A}\|\|^2$	squared Frobenius norm of matrix $\mathbf{A}$
$\mathbf{A}^*$	conjugate and transpose of a matrix $\mathbf{A}$
A_d	number of paths of Hamming weight d that merge with the all-zero paths
A_e	effective aperture area of the receiver antenna
$A \cap B, AB$	intersection of set A and set B, A and B
$A \cup B, A + B$	union of set A and set B, A or B
a	Gaussian filter parameter
$a(h_R)$	correction factor in Hata model
a_f	frequency sensitivity
a_k	Fourier series coefficients
B	bandwidth
B_d	information weight (number of information bit errors) of all paths of Hamming weight d
$\boldsymbol{B}_{d_{free}}$	information weight (number of information bit errors) of all paths of Euclidean distance d_{free} of TCM
C	channel capacity in coded bits/input symbol, correlation
$\mathbf{C}$	channel capacity in coded bits/second
C_o	outage capacity
$c(\boldsymbol{D}_K)$	correlation metric in MLSD
C_N	correlation metric in CPM
$C_X(t_1, t_2)$	autocovariance of the random process $x(t)$
$C(z)$	transfer function of causal ZF-LE, z-transform of the sequence $c(k)$
$Cov(N_j N_k)$	covariance of two noise samples
$\boldsymbol{c}$	code word, PN sequence
c_i	a coded bit, a differentially coded bit
$c(t)$	PN function of N chips
$\boldsymbol{c}(t)$	complex PN function
$c_I(t)$	PN function of I-channel
$c_Q(t)$	PN function of Q-channel
$c(\boldsymbol{x}\|\boldsymbol{H}_i)$	metric for CPM demodulation
D_i	ith symbol in the symbol stream

d	distance
$\boldsymbol{d}$	data sequence
dB	decibel
d_{free}	free distance of a convolutional code
$\boldsymbol{d}_{free}$	Euclidean free distance of TCM
d_i, $d(i)$	normalized bit or symbol amplitude, $d_i \in \{-1, +1\}$, $d_i \in \{0, 1)$
$\{d_i\}$, $\{d(i)\}$	data sequence
d_{min}	minimum Hamming distance, minimum Euclidean distance
$d(u,v)$	Hamming distance between two code words
$d(\boldsymbol{x}, \boldsymbol{s}_i)$	Euclidean distance between two vectors
E	energy (with or without a subscript), smallest symbol energy in MQAM or MASK, electric-field wave, elevation angle
E_b	bit energy
$\mathcal{E}_b$	diversity bit energy
$E(d,t)$	free space E-field at distance d from transmitter and time t
E_h	hop energy
$EIRP$	effective isotropic radiated power
E_0	free space E-field at distance d_0 from transmitter
E_s	symbol energy
$\mathcal{E}_s$	diversity symbol energy
$\mathbf{E}(X)$	expected value (mean value) of X
$\mathbf{E}(X^2)$	mean-square value of X^2
e	2.718
$\boldsymbol{e}$	error word
$e(k)$	error sequence of MSE-LE
$e(t)$	error process
F	noise figure
$F\{x(t)\}$	Fourier transform of $x(t)$
$F(z)$	minimum-phase transfer function, transfer function of a synthetic channel, z-transform of the sequence $f(k)$
$F^*(1/z^*)$	maximum-phase function
$F^{-1}\{X(f)\}$	inverse Fourier transform of $X(f)$
${}_2F_1$	Gauss hypergeometric function
$F^{(-1)}_{\lvert h\rvert^2}(p_o)SNR$	outage signal-to-noise ratio
$F_X(x)$	distribution function of X
$F_{XY}(x, y)$	joint distribution function of X and Y
$f_{\lvert h\rvert}(x)$	density function of the channel tap magnitude $\lvert h\rvert$
$f_{XY}(x, y)$	joint density function of X and Y
$f_{X\lvert Y}(x\lvert y)$	conditional density function of X given Y
f	frequency, Doppler shift

f_c	carrier frequency
f_D	Doppler spread
f_j	instantaneous carrier frequency of FH
$f_{L,i}$	instantaneous local carrier frequency of a frequency synthesizer
f_m	maximum Doppler shift
f_s	sampling frequency
$f_X(x)$	density function of X
$f_{\boldsymbol{X}}(\boldsymbol{x})$	density function of vector $\boldsymbol{X}$
G	amplifier gain, gain of a two-port network
$\mathbf{G}$	generator matrix, space-time block code matrix
$\boldsymbol{G}$	TCM asymptotic coding gain
G_{DC}	gain of a downconverter
G_{LNA}	gain of a low-noise amplifier
G_R	receiver antenna gain
G_R/T_s	antenna gain-to-noise temperature ratio of the earth station
G_S/T_{sat}	antenna gain-to-noise temperature ratio of the satellite
G_T	transmitter antenna gain
g	parity
$g(t)$	pulse
$g_n(t)$	orthonormal pulse shapes in OFDM
$g(x)$	code generator polynomial
$\mathbf{H}$	Hadamard matrix (with or without a subscript), parity check matrix, channel tap matrix
H	source entropy in bits/second
H_i	hypothesis
$H(f)$	transfer function or frequency response
$H_{FE}(f)$	transfer function of the front-end filter of the receiver
$\lvert H(f)\rvert$	magnitude response (amplitude response)
$H_T(f)$	transfer function of transmit filter
$H_R(f)$	transfer function of receive filter
$H(k)$	N-point DFT of the sequence $h(n)$
$H(X)$	entropy of the discrete random variable (discrete source) X
h	Planck constant, digital modulation index, complex channel tap
$\mathbf{h}$	row vector of a Hadamard matrix
$\hat{\boldsymbol{h}}$	MMSE of the vector $\boldsymbol{h}$
$h_i,\ h(i)$	ith channel tap
$\tilde{h}(i)$	complex channel tap
$h_L(t)$	complex envelope of the impulse response $h(t)$
$h(n)$	sequence used in OFDM
h_R	receive antenna height

h_T	transmit antenna height
$h(t)$	impulse response
$h(\boldsymbol{X})$	differential entropy of a continuous random variable X
$h(X\|Y)$	conditional differential entropy of a continuous random variable X
$h(\boldsymbol{X})$	differential entropy of a continuous n-dimensional random vector $\boldsymbol{X}$
$h(x)$	monic binary irreducible primitive polynomial, PN code polynomial
I	interference power, photodiode current
I_m	interchannel interference
I	MUI variable
$I(X)$	self-information of the discrete random variable (discrete source) X
$I(u_i, v_j)$	pair-wise mutual information
$I(U, V)$	mutual information
$I_0(\bullet)$	modified Bessel function of the first kind of zero order
$I_n(\bullet)$	modified Bessel function of the first kind of nth order
J	jamming variable
$J_0, J_0(\bullet)$	jamming spectral density, Bessel function of zero order
K	number of simultaneous users in CDMA, Kelvin
$\mathbf{K}$	covariance matrix
k	integer, Boltzmann constant, number of information bits in a block code, number of inputs of a convolutional encoder
k_0	free space wave number
k/n	code rate
L_C	path loss
L	diversity order, loss of a two-port network
$L(f)$	transfer function of an equalizer
L_r	receive antenna diversity
L_s	number of symbol times for m transmitted symbols in transmit diversity
L_{TL}	loss of a transmission line
L_t	transmit antenna diversity
L_{dB}	mean value in decibels of the log-normal density variable
$L(\lambda, P_1, \ldots, P_n)$	Lagrangian
l	length of a code word
$\bar{l}$	average length of a code word
ln	natural logarithm
$\ln \Lambda(X\|y)$	conditional ln-likelihood ratio
log	base-10 logarithm
$\log_2$	base-2 logarithm
M	number of distinct M-ary symbols
$\mathbf{M}(\boldsymbol{r} \mid \boldsymbol{c})$	path metric in Viterbi algorithm or log-likelihood function
m	mean value of a random variable, Nakagami-m parameter

$m_A(X^{-1})$	arithmetic mean of $1/X(f)$
$m_G(X)$	geometric mean of $X(f)$
m_n	metric for OFDM timing synchronization
$m(t)$	message signal
$\mathbf{m}_{ij}^{(l)}$	message sent by the bit node i to check node j at the lth iteration
$\hat{\mathbf{m}}_{ji}^{(l)}$	message sent by the check node j to bit node i at the lth iteration
m_l^2	sum of the squares of the means
$m_X(t)$	mean value of the random process $x(t)$
N	noise variable, available noise power, number of OFDM subcarriers, period of a PN sequence
$\boldsymbol{N}$	noise vector, complex noise
$\mathcal{N}$	noise variable at detector input
N	noise variable
$\mathfrak{N}$	complex noise variable, complex noise vector
$N(f)$	power spectral density of the equivalent lowpass noise $n(t)$
N_D	number of branches in a frequency bin determinator
N_H	number of hop bins
N_i	system noise power
N_n	average number of nearest neighbors of a signal vector
$N(0, \sigma^2)$	Gaussian random variable with zero mean and variance σ^2
$\boldsymbol{N}(0, \sigma^2)$	Gaussian vector with iid components of zero mean and variance σ^2
N_k	noise sample
$N_0/2$	power spectral density of noise
$\mathcal{N}_V$	average number of level crossings
n	code word length, path loss exponent
$n_I,\ N_I$	in-phase noise variables
$n_Q,\ N_Q$	quadrature noise variables
(n,k)	block code of k information bits and code word length n
$n(t)$	noise
$n_L(t)$	complex envelope of bandpass noise
$n_0(t)$	output noise of a matched filter
P	power
$P_{c,h}$	probability of correctly identifying the frequency bin
$P(d)$	pair-wise error probability ($\Pr(\boldsymbol{c} \to \boldsymbol{c}')$)
P_e	error probability (bit, symbol, code word)
$P(f)$	energy spectrum, Fourier transform of pulse shape $p(t)$
P_j	power of a jamming signal
P_p	peak power
$\Pr(A)$	probability of A
$\Pr(A,B)$	joint probability of A and B

$\Pr(A\|B)$	conditional probability of A given B
$\Pr(\boldsymbol{c} \to \boldsymbol{c}')$	pair-wise error probability
$\Pr(\boldsymbol{c} \mid \boldsymbol{r})$	a posteriori probability
$\Pr(\boldsymbol{r} \mid \boldsymbol{c})$	likelihood of the transmitted code vector $\boldsymbol{c}$
P_T	transmit power
$P(z)$	linear predictor in MSE-DFE
p	crossover probability of a BSC, probability of a binary symbol
p_{out}	outage probability
$p_{UV}(u_i, v_j)$	joint distribution of u_i, v_j
$p(v_j\|u_i)$	transition probability of a discrete channel
$p_X(x_i)$	distribution of the discrete random variable X, $i = 1, 2, \ldots, n$
$p(t)$	pulse shape
$\boldsymbol{Q}(a, b)$	Marcum $\boldsymbol{Q}$-function
$Q(x)$	Gaussian integral Q-function of argument x
$Q(z)$	transfer function of the composite channel in suboptimum MSE-LE
q	optimum number of jamming tones
R	resistance, Rayleigh random variable, source rate in symbols/second
R_b	bit rate
R_c	chip rate
$\boldsymbol{\mathcal{R}}$	responsivity
R_e	Earth's radius (6378 km)
$R_h(\tau, \boldsymbol{t}')$	multipath autocorrelation profile
$R_{h_i}(\boldsymbol{t}')$	ith path autocorrelation
$R(i-j)$	autocorrelation of the data sequence $\{d_i\}$
R_s	symbol rate
$R(t)$	envelope of a bandpass process
$\boldsymbol{\mathcal{R}}_V$	level crossing rate
R_w	Walsh chip rate
$R_x(\tau)$	autocorrelation of WSS random process $x(t)$
$R_X(t_1, t_2)$	autocorrelation of the random process $x(t)$
r	value assumed by a random variable R, code rate, spectral efficiency
$\boldsymbol{r}$	received word
r^2	signal-to-intertone interference ratio
r_e	extinction ratio
S	input variable of a Gaussian channel
$\boldsymbol{S}$	input vector of a Gaussian channel
$\boldsymbol{S}$	sample space
$S(f)$	power spectral density (with or without a subscript)
$S_h(\tau, \boldsymbol{f}')$	multipath Doppler profile
$S_{h_i}(\boldsymbol{f}')$	ith path Doppler power spectrum

$\boldsymbol{s}$	syndrome vector, orthogonal covering symbol
$\mathrm{sgn}\,(x)$	signum function
$\mathrm{sign}[x]$	sign of x
$s(t)$	digital signal
$\{s_i(t)\}$	set of M digital signals, $i = 1, 2, \ldots, M$
$\{\boldsymbol{s}_i\}$	set of M signal vectors in the signal space, $i = 1, 2, \ldots, M$
$\lVert\boldsymbol{s}_i\rVert$	norm of signal vector $\boldsymbol{s}_i$
s_{ik}	coefficients of the Gram–Schmidt orthogonal expansion, I–Q values of a two-dimensional signal vector
$s_L(n)$	time samples of an OFDM signal
$s_L(t)$	complex envelope a bandpass signal $s(t)$
$s_0(t)$	output signal of a matched filter
s_p	pilot symbol
T	time interval, period, sampling period
$\mathbf{T}$	phase error rotation matrix
T_A	antenna noise temperature
T_b	bit time
T_c	chip time, channel coherence time
T_d	time delay, multipath delay spread
T_{DC}	effective noise temperature of a downconverter
T_{DM}	effective noise temperature of a demodulator
T_e	effective noise temperature
T_h	hop time
T_{LNA}	effective noise temperature of a low-noise amplifier
T_n	physical temperature of the resistor
T_0	reference temperature, time interval, period
T_p	pulse width
$Tr(\mathbf{A})$	trace of matrix $\mathbf{A}$
T_s	symbol time, system noise temperature
t	time, error-correcting capability of a block code
U	set of M input symbols of a discrete channel
$\bigcup_{i=1}^{M} A_i$	union of A_i set
$u(t)$	unit step function
$\boldsymbol{u}$	message vector
V	voltage, set of Q output symbols of a discrete channel
$\mathrm{Var}(X)$	variance of X
V_{rms}	root mean-square voltage
V_T	threshold voltage
v	radial velocity
$v(t)$	voltage signal

W	bandwidth, watt
$\{w_n(t)\}$	set of Walsh functions, $n = 1, 2, \ldots, M$
X	random variable, discrete source, output variable of a Gaussian channel or a matched filter
$\boldsymbol{X}$	random vector, output vector of a Gaussian channel
$\overline{X}$	mean value (expected value) of X
$\overline{X^2}$	mean-square value of X^2
$X\left(e^{j2\pi f'}\right)$	discrete-time Fourier transform of the sequence $x(k)$
$\lvert X(f)^2 \rvert$	energy spectral density of the energy signal $x(t)$
$X(f)$	Fourier transform of $x(t)$, folded spectrum
$X(k)$	N-point DFT of the sequence $x(n)$
X^n	nth extension of the discrete source X
$X_T(f)$	Fourier transform of $x_T(t)$, $2T$-truncation of $x(t)$, $-T \le t \le T$
$X(z)$	z-transform of the sequence $x(k)$, transfer function of the composite channel in optimum MSE-LE
x	value assumed by a random variable X
$\boldsymbol{x}$	value assumed by a random vector $\boldsymbol{X}$
$\lfloor x \rfloor$	integer part of x
$x(n)$	discrete-time signal, sequence used in OFDM
$x(t)$	continuous-time signal (with or without a subscript)
$x_I(t)$	in-phase component of the bandpass signal $x(t)$
$\{x_k(t)\}$	set of L orthonormal basis functions, $k = 1, 2, \ldots, L$
$\{\mathbf{x}_k\}$	set of L orthonormal basis vectors, $k = 1, 2, \ldots, L$
$x_L(t)$	complex envelope (equivalent lowpass signal) of the bandpass signal $x(t)$
$x_p(t)$	periodic signal
$x_Q(t)$	quadrature component of the bandpass signal $x(t)$
$x_s(t)$	sampled function
$x_T(t)$	$2T$-truncation of $x(t)$, $-T \le t \le T$
$Y(k)$	N-point DFT of the sequence $y(n)$
$y(n)$	sequence
$y(t)$	continuous-time function
$\boldsymbol{Z}$	pre-mapped vector at the input of the combiner
$Z(k)$	frequency samples of an OFDM signal (the I–Q values of symbols of OFDM subcarriers)
Z_0	amplifier transimpedance
$z_k(t)$	complex envelope of the kth OFDM subcarrier
$*$	linear convolution
$\otimes$	circular convolution
$(\ )^*$	complex conjugate
α	arbitrary constant

α_n	normalized signal amplitude in MQAM
α_p	complex Doppler factor
$\lvert\alpha_p\rvert$	Doppler loss factor
β	proportionality constant, roll-off factor of a raised-cosine filter
γ	threshold
$\gamma_{k,m}$	complex Doppler loss factor
γ_n	MSK data stream
Γ	ground reflection coefficient, gamma function
ΔF	frequency offset in OFDM
Δf	peak frequency deviation
$\Delta\varepsilon_l$	differential Doppler phase error
$\Delta\hat{\varepsilon}_{l-1}$	post-estimated differential Doppler phase error
$\Delta\varepsilon_l - \Delta\hat{\varepsilon}_{l-1}$	double-differential Doppler phase error
δ	jamming pulse duty cycle, fraction of FH bandwidth being jammed, fraction of a hop being jammed
δ_{ij}	0 for $i \neq j$ and 1 for $i = j$
$\delta(t)$	unit impulse function
ε	phase error
ε_l	Doppler phase error
θ	phase
θ_k	azimuth angle of the kth wave
θ_L	Earth station longitude
θ_ℓ	Earth station latitude
θ_S	GEO satellite longitude
$\theta(t)$	phase function
λ	wavelength, Lagrange multiplier
μ	conditional mean value
$\Lambda(\mathrm{X}\lvert\boldsymbol{y})$	conditional likelihood ratio
Π	product, fractional coverage area
ρ	spatial correlation coefficient
$\rho_X(\boldsymbol{\tau})$	normalized autocovariance of the random process $x(t)$
σ^2	variance of noise
σ_{dB}	standard deviation of the log-normal density variable in decibels
σ_X^2	variance of the random variable X
σ_s^2	power of the diffuse paths
τ	time delay variable, average fade duration
$\tau_i(t)$	path delay
φ	phase state in CPM
φ_k	polar angle of the kth wave
ϕ	impossible event, null set, phase in MFSK and CPM, phase shift

$\Phi_0(f)$	power spectral density of the equalizer output noise
$\{\phi_k(t)\}$	set of orthonormal eigenfunctions of the noise autocorrelation
χ	voice activity factor or data duty cycle
χ^2	chi-square
ψ	angle of mobile direction with respect to the x-axis, Doppler phase error
$\Psi(f)$	power spectral density of sampled noise
$\Psi_0(f)$	power spectral density of output noise of ZF-LE
$\Psi(t)$	phase of a bandpass process
Ω	mean-square value of the envelope of the Nakagami-m process

Abbreviations

2G	second generation
3G	third generation
A/D	analog/digital conversion
AGN	additive Gaussian noise
AMPS	advanced mobile phone system
APD	avalanche photodiode
ASK	amplitude shift keying
AWGN	additive white Gaussian noise
BCH	Bose–Chaudhuri–Hocquenghem code
BEC	binary erasure channel
BPA	belief propagation algorithm
BSC	binary symmetric channel
CDM	code division multiplexing
CDMA	code division multiple access
CDMA 2000	3G CDMA
CP	cyclic prefix
CPM	continuous phase modulation
CP-MFSK	continuous phase M-ary frequency shift keying
CRC	cyclic redundancy check
CSI	channel side information
CSIR	channel side information at the receiver
CSK	code shift keying
D/A	digital/analog conversion
DD-DF	double-differential decision-feedback algorithm
D-DF	differential decision-feedback algorithm
DEMUX	demultiplexer
DFS	decision-feedback selection
DFT	discrete Fourier transform
DMC	discrete memoryless channel
DMPSK	differential M-ary phase shift keying
DMQAM	differential quadrature amplitude modulation
DPSK	differential phase shift keying
DQPSK	differential quadrature phase shift keying

DSB-AM	double sideband–amplitude modulation
DS	direct sequence
DS-CSK	direct sequence–code shift keying
DS-PSK	direct sequence–phase shift keying
DS-SS	direct sequence spread spectrum
DTFT	discrete-time Fourier transform
EGC	equal gain combining
EIRP	effective isotropic radiated power
ESN	electronic serial number
ETACS	extended total access cellular system
FCC	Federal Communications Commission
FDM	frequency division multiplexing
FDMA	frequency division multiple access
FFH	fast frequency hop
FFT	fast Fourier transform
FH	frequency hop
FIR	finite impulse response
FM	frequency modulation
FSE	fractionally spaced equalizer
FSK	frequency shift keying (binary frequency shift keying)
fT	frequency–time product
GEO	geostationary orbit
GMSK	Gaussian minimum shift keying
GPS	global positioning system
GSM	global system for mobile communication
$\|h\|^2 SNR$	instantaneous SNR
ICI	intercarrier interference
ICI	interchannel interference
IDFT	inverse discrete Fourier transform
IEEE	Institute of Electrical and Electronics Engineers
IFFT	inverse fast Fourier transform
iid	independent and identically distributed
IIR	infinite impulse response
IPI	intrapath interference
IS	interim standard
ISI	intersymbol interference
$\mathcal{ISI}$	intersample interference
JDC	Japanese digital cellular system
JTACS	Japanese total access communication system
LDPC	low-density parity-check code

LFSR	linear feedback shift-register
LLR	ln-likelihood ratio
LR	likelihood ratio
L-REC	rectangular pulse of duration L symbols
L-RC	raised cosine pulse shape of duration L symbols
LSB	lower sideband
LTI	linear time-invariant
MAP	maximum a posteriori
MASK	M-ary amplitude shift keying
MFSK	M-ary frequency shift keying
MIMO	multiple-input multiple-output
MIN	mobile identification number
MIP	multipath intensity profile
MISO	multiple-input single-output
ML	maximum likelihood
MLSD	maximum likelihood sequence detection
MMSE	minimum mean-square error
MPA	message passing algorithm
MPSK	M-ary phase shift keying
MQAM	quadrature amplitude modulation
MRC	maximal ratio combining
MSC	mobile switching center
MSE-DFE	mean-square error decision-feedback equalizer
MSE-LE	mean-square error linear equalizer
MSK	minimum shift keying
MUI	multi-user interference
MUX	multiplexer
NAMPS	narrowband advanced mobile phone system
NRZ	non-return-to-zero
NTACS	narrowband total access communication systems
OFDM	orthogonal frequency division multiplexing
OOK	on–off keying
OQPSK	offset quadrature phase shift keying
PCS	personal communication system
PD	pin photodiode
PDC	Pacific (or personal) digital cellular system
PDF	probability distribution function
pdf	probability density function
$\pi/4$-DQPSK	$\pi/4$ shift differential quadrature phase shift keying
PLL	phase-locked loop

PN	pseudo-noise
PSK	phase shift keying (binary phase shift keying)
PSTN	public switched telephone network
QPSK	quadrature phase shift keying
RS	Reed–Solomon code
SC	selection combining
SCM	station class mark
SFH	slow frequency hop
SIMO	single-input multiple-output
$SINR$	signal-to-interference and noise ratio
$\boldsymbol{SINR}$	path signal-to-interference-and-noise ratio
$SINR_0$	output signal-to-interference plus noise ratio
SIR	signal-to-interference ratio
SIR_i	input signal-to-interference ratio
SIR_0	output signal-to-interference ratio
$SJNR_0$	output signal-to-jamming-plus-noise ratio
SJR_i	input signal-to-jamming ratio
$SJR_{i,\,p}$	input signal-to-pulse jamming ratio
SJR_0	output signal-to-jamming ratio
$SJR_{0,\,p}$	output signal-to-pulse jamming ratio
SNR	signal-to-noise ratio
$\boldsymbol{SNR}$	diversity symbol signal-to-noise ratio
SNR_0	output signal-to-noise ratio
SPA	sum product algorithm
TCM	trellis coded modulation
TDMA	time division multiple access
TIA/EIA	Telecommunication Industry Association/Electronic Industry Association
USB	upper sideband
USDC	US digital cellular
VCO	voltage-controlled oscillator
WCDMA	wideband CDMA (3G CDMA)
WLAN	wireless local area network
WMAN	wireless metropolitan area network
WSCS	wide-sense cyclostationary
WSS	wide-sense stationary
ZF-DFE	zero-forcing decision-feedback equalizer
ZF-LE	zero-forcing linear equalizer