Symbols

This list gives a brief overview of the use of variables in the text. Due to the large number of quantities occurring, the same letter might be used in different chapters for different quantities. For this reason, this will need checking as chapter numbers have changed in which the variable is primarily used, though they can occur in other chapters as well. Those variables that are used only locally, and explained directly at their occurrence, are not mentioned here.

Lowercase symbols:		
a_p, a_m	auxiliary variables	4
a_1	amplitudes of the MPCs	5, 6, 7, 8
$a(h_m)$	auxiliary function	7
$\mathbf{a}(\phi)$	steering vector	8
$a_{n,m}$	amplitudes of components from direction n, delay m	13
b_m	mth bit	11, 12, 13, 14, 16, 17
cdf	cumulative distribution function	5
$c_{i,k}$	amplitudes of resolvable MPCs; tap weights for tapped delay lines	7
c_0	speed of light	5, 13, 19
c_m	complex transmit symbols	11, 12, 13, 16
d	distance BS–MS	4
d	distance in signal space diagram	12, 13
d_{R}	Rayleigh distance	4
d_{break}	distance BS–breakpoint	4
d_{layer}	thickness of layer	4
d_{direct}	direct pathlength	4
d_{refl}	length of reflected path	4
d_{p}	distance to previous screen	4
d_{n}	distance to subsequent screen	4
d_0	distance to reference point	5
d_{a}	distance between antenna elements	8, 13
d_{w}	distance between turns of helix antenna	8
d_{km}	euclidean distance between signal points with index k and m	11
$d(\vec{x}, \vec{y})$	distance of codewords	14
d_H	Hamming distance	14
d_{cov}	coverage distance	3
d_{div}	diversity order	20
e	basis of natural logarithm	

$e(t)$	impulse response of equalizer	16
f	frequency	5
$f(\ )$	function	
f_c	carrier frequency	5, 7, 8
f_{rep}	repetition frequency	8
f_{slip}	frequency slip	8
f_{inst}	instantaneous frequency	12
f_k	impulse response of discrete-time channel	16
f_n	carrier frequencies in OFDM	19
f_D	modulation frequency in FSK	11
$\mathbf{g}$	network encoding vector	22
$g(\ )$	function	
$g(t)$	basis pulse	11, 12, 19
$g_R(t)$	rectangular basis pulse	11
$\tilde{g}(t)$	phase pulse	11
g_m	discrete impulse response of channel plus feedforward filter	16
g_N	Nyquist raised cosine pulse	11
g_{NR}	root Nyquist raised cosine pulse	11
$h(t, \tau)$	channel impulse response	2, 6, 7, 8, 12, 13, 18, 19, 20
h_{TX}	height of TX	4
h_{RX}	height of RX	4
h_s	height of screen	4
h_b	height of BS	7
h_m	height of MS	7
$h_{r,d}$	complex channel gain from relay to destination	22
h_{roof}	height of rooftop	7
$h_{meas}(t_i, \tau)$	measured impulse response	8
$h_{s,d}$	complex channel gain from source to destination	22
$h_{s,r}$	complex channel gain from source to relay	22
h_w	height of helix antenna	9
$h(t, \tau, \phi)$	directionally resolved impulse response	7
h_{mod}	modulation index of CPFSK signal	11
$\mathbf{h}_d$	vector of desired impulse responses	13, 20
i	index counter	
j	index, imaginary unit	4
k, k_0	wavenumber	4, 13
k	index counter	8, 11, 13, 19, 20, 22, 28
k_{scale}	scaling factor for STDCC	8
k_B	Boltzmann constant	3
l	index counter	8, 19, 20
m	Nakagami m-factor	5, 13
m	counter	11, 12, 13, 14, 16, 17
m	index for parity check bits	14
n	propagation exponent	4, 7

n_1	refraction index for medium	4
$n(t)$	noise signal	8, 12, 13, 14, 16, 18
$n_{\mathrm{LP}}(t)$	low-pass noise	12
$n_{\mathrm{BP}}(t)$	bandpass noise	12
n	index counter	11
n_m	sampled noise values	16, 19
n_n	sampled noise values	14, 21
$\mathbf{n}$	vector of noise samples	20
$\tilde{n}_m$	sample values of colored noise	
p	transition probability	14
pdf	probability density function	5
$p(t)$	modulated pulse	8
$p(t)$	pulse sequence	11
q_m	impulse response of channel + equalizer	16
$\mathbf{r}$	position vector	4
r	absolute value of fieldstrength	5
r	spectral efficiency	14
$r_{\mathrm{LP}}(t)$	low-pass representation of received signal	12
$\mathbf{r}$	received signal vector	12
$r(t)$	received signal	14, 15, 16
s	subcarrier channel index	28
$s(t)$	sounding signal	8
$s_1(t)$	auxiliary signal	8
$s_{\mathrm{LP,BP}}(t)$	low-pass (bandpass) signal	11
$\mathbf{s}_{\mathrm{LP,BP}}$	signal vector in low-pass (bandpass)	11
$\mathbf{s}_{\mathrm{synd}}$	syndrome vector	14
$\mathbf{s}$	vector of signals at antenna array	8, 20, 27, 28
$\mathbf{s}$	transmit signal vector	14
t	absolute time	2, 11, 12, 13, 16, 17
$\mathbf{t}$	precoding vector	20
t_0	start time	6
t_{s}	sampling time	12
u	auxiliary variable	11
u_m	sequence of sample values at equalizer input	16
$\mathbf{u}$	vector of information symbols	14
v	velocity	5
$\mathbf{v}$	singlar vector	20
w_l	antenna weights	8, 13, 20
x	x-coordinate	4
x	general variable	5
x	transmit signal	22
$x(t)$	input signal	6
$\mathbf{x}$	code vector	14
$\mathbf{x}$	sequence of transmit signals	14
y	y-coordinate	4
y	decision variable	21
y	received signal	22
$\mathbf{y}$	sequence of receive signals	14

$y(t)$	output signal	6
z	z-coordinate	
Uppercase symbols:		
$\mathbf{A}$	steering matrix	8
$\mathbf{A}$	antenna mapping matrix	27
A_{RX}	antenna area of receiver	4
$A(d_{\mathrm{TX}}, d_{\mathrm{RX}})$	amplitude factors for diffraction	4
ADF	average duration of fades	
A	amplitude of dominant component	7
A	state in the trellis diagram	14
$B(\nu f)$	Doppler-variant transfer function	6
B_{coh}	coherence bandwidth	6
B	bandwidth	11
BER	bit error probability	12
B_{n}	noise bandwidth	12
B_{r}	receiver bandwidth	12
B	state in the trellis diagram	14
B_{G}	bandwidth of Gaussian filter	11
C	capacity	14, 17, 20
$\mathbf{C}$	covariance matrix	
C_{crest}	crest factor	8
C	proportionality constant	
C	state in the trellis diagram	14
D	diffraction coefficient	5
D_{W}	diameter of helix antenna	8
D	quadratic form	12
D	maximum distortion	16
D	state in the trellis diagram	14
D	unit delay	27
D_{leav}	interleaver separation	14
D	antenna directivity	
E	electric fieldstrength	4
E_{diff}	fieldstrength of diffracted field	4
E_{inc}	fieldstrength of incident field	4
$E\{\}$	expectation	4, 13, 14, 18
$E1$, $E2$	fieldstrength of multipath components	5
E_0	normalization fieldstrength	13
E_{S}	Symbol energy	11, 12, 13
E_{B}	bit energy	11, 12, 13
E_{C}	chip energy	18
$E_{s,k}$	energy of kth signal	11, 18
$E(f)$	transfer function of equalizer	16
$F(\nu_{\mathrm{F}})$	Fresnel integral	4
$\tilde{F}$	modified Fresnel integral	4
F	local mean of fieldstrength	5
$F(z)$	factorization of the transfer function of the equivalent time discrete channel	16
F	noise figure	3
G_{RX}	antenna gain of receive antenna	3, 4

G_{TX}	antenna gain transmit antenna	4
$G(D)$	code polynomial	27
$G(\gamma)$, $G(\varphi, \theta)$	antenna pattern	5
$G(\nu, \nu_1, \nu_2)$	Gaussian function	7
$G_{\max}$	maximum gain	
G_{R}	spectrum of rectangular pulse	11
G_{N}	spectrum of Nyquist pulse	11
G_{NR}	spectrum of root Nyquist pulse	11
$\mathbf{G}$	generator matrix	14
G_{code}	code gain	14
$\mathbf{G}_{\mathrm{G}}$	matrix with iid Gaussian entries	20
G	gain of an amplifier stage	3
H	transfer function of the channel	5, 6, 19, 20
$H(X)$	entropy	14
$H_D(X)$	entropy of binary symmetric channel	14
$H_R(f)$	transfer function of receive filter	12, 18
$\mathbf{H}$	parity check matrix	14
$\mathbf{H}_{\mathrm{had}}$	Hadamard matrix	18, 19
$I(t)$	in-phase component	5
$I(t)$	link control action	22
$I(x, y)$	mutual information	14
I_0	modified Bessel function	5, 12
$\lvert J \rvert$	Jacobi determinant	5
J_0	Bessel function	7
K_r	Rice factor	5
$K(t, \tau)$	kernel function	6
K	number of resolvable directions	8
K_I	system margin	3
K	number of bits in a symbol	11
K	number of information symbols in a codeword	14
$2K + 1$	number of equalizer taps	16
K	scaling constant for STDCC	8
K	number of users	20
K	number of relays	22
L	number of clusters	7
L_{msd}	multiscreenloss	
L_{rts}	diffraction loss	7
L_{ori}	street orientation loss	7
L_{a}	antenna dimension	4
L_i	attenuation at the ith screen	
L_{c}	correlation length	4
L	duration of the impulse response of the equivalent time discrete channel f	16
L	number of cells in convolutional encoder	14
L	number of data streams	20
$\tilde{L}$	dimension of space-time code	20
L_{Tr}	truncation depth	14
L_{symb}	number of symbols where two possible sequences differ	14

L_{f}	losses in feeder	3
L	number of RF chains in HS-MRC	
$M(\phi, \theta)$	array factor	8
M	number of elements in the alphabet	11
$M(s)$	moment-generating function	12, 13
N	number of screens	4
N	number of MPCs	5, 7, 8
N	size of the set of expansion functions	12
N	total number of symbols in the code	14
N	number of mod-2 adders in the convolutional encoder	14
N_0	noise power-spectral density	12
$N(f)$	noise spectrum	6, 12
N_{symb}	number of information bits/symbols in TCM	14
$\tilde{N}$	number of bits for convolutional encoder in TCM	14
N	number of users in MA	17
N_{reg}	length of shift register	14
N_{r}	number of receive antennas	8, 13, 20
$N_{\mathrm{subchannel}}$	number of subchannels	28
N_{t}	number of transmit antennas	13, 20
N_{s}	number of significant scatterers	20
N_{BS}	number of BS antennas	20
N_{MS}	number of MS antennas	20
N_{R}	level crossing rate	5
P_{TX}	transmit power	4
P_{RX}	receive power	4
P_{m}	average power	5
$P_{h,S,B}$	cross-power spectral densities	6
$P_{\mathrm{h}}(\tau)$	PDP	6
$P(t, \tau)$	instantaneous PDP	7
P_{n}	noise power	
P_{pair}	pairwise error probability	12
P_{inst}	instantaneous received power	12
P_{max}	maximum TX power	20
P_{f}	false alarm probability	21
P_{md}	missed detection probability	21
P_{s}	transmit power of source	22
P_{r}	transmit power of relay	22
Pr	probability	
$\mathrm{Pr}_{\mathrm{out}}$	outage probability	
PL	pathloss	4, 5
P_{s}	signal power	3, 11
$Q(x)$	Q-function	12, 13
Q	antenna quality	9
Q	codebook size	20
Q	queue backlog	22
Q	quantization function	23
$Q(t)$	quadrature component	5
Q_{T}	interference quotient	6

Q_M	Marcum's Q-function	12
$Q(z)$	transfer function of equivalent channel and equalizer	16
R	radius of circle	5
R	cell size	17
R	transmission rate	14
R_{th}	threshold transmission rate	22
$\mathbf{R}_{\text{TX}}$	transmit correlation matrix	6, 7, 20
$\mathbf{R}_{\text{RX}}$	receive correlation matrix	6, 7, 20
R_{xx}	autocorrelation function of x	11
$\mathbf{R}_{xx}$	correlation matrix of x	8
R_{rad}	radiation resistance	8
R_{S}	symbol rate	11
R_{B}	bit rate	11
R_{c}	code rate	14
R_{e}	rank of error matrix	17
R_h	impulse response correlation function	6
$\mathbf{R}_{\text{ni}}$	noise and interference correlation matrix	20
$\tilde{R}_{yy}(t, t')$	autocovariance signal of received signal	7
SIR	signal-to-interference ratio	5
$S(f)$	power spectrum	5, 6, 12
$S(t)$	topology state	22
$S(\nu, \tau)$	spreading function	6
S_τ	delay spread	6
$S_{\text{D}}(\nu, \tau)$	Doppler spectrum	7
$S_{\text{LP,BP}}(f)$	power spectrum of LP (BP) signal	11
SER	symbol error probability	12
S_{N}	noise power-spectral density	
S_ϕ	angular spread	6, 7, 13
T_{B}	bit duration	
T	transmission factor	4
T_{m}	mean delay	6
$T_{\text{m}}(t)$	instantaneous mean delay	6
T_{rep}	repetition time of pulse signal	8
TB	time bandwidth product	8
T_{slip}	slip period	8
$\mathbf{T}$	auxiliary matrix	8
$\mathbf{T}$	transmit beamforming matrix	20
T	duration (general)	11
T_{per}	periodicity	11
T_{s}	sampling time	
T_{S}	symbol duration	11
T_{p}	packet duration	17
T_{cp}	duration of cyclic prefix	19
T_{C}	chip duration	18
T_{e}	temperature of environment	3
T_{d}	delay of pulse in PPM	11
T_{coh}	coherence time	6
T_{g}	group delay	12
$\mathbf{U}$	unitary matrix	8, 20

W	correlation spectrum	4
W_a	delay window	6
W	system bandwidth	
$\mathbf{W}$	unitary matrix	19
X	complex Gaussian random variable	12
$X(x)$	code polynomial	14
Y	complex Gaussian random variable	12
Z	complex Gaussian random variable	12
Z	virtual queue backlog	22

Lowercase Greek:

α	dielectric length	4
α	complex channel gain	12
α	rolloff factor	11
α	steering vector	8
β	decay time constant	7
β	amplification at relay	22
γ	SNR	
$\overline{\gamma}$	mean SNR	
γ_{MRC}	SNR at output of maximum ratio combiner	13
γ_{EGC}	SNR at output of equal gain combiner	13
γ	angle for Doppler shift	5
γ_S	E_S/N_0	12
γ_B	E_B/N_0	12, 13, 16, 17
δ	complex dielectric constant	4
δ_{ik}	Kronecker delta	13, 16, 19
$\delta(\tau)$	Dirac function	12, 13, 16, 18
$\in$	dielectric constant	4
$\in_{\mathrm{r}}$	relative dielectric constant	4
$\in_{\mathrm{eff}}$	effective relative dielectric constant	4
ε_m	error signal	16
ε	error vector of a code symbol	14
φ	orientation of a street	7
φ	phase of an MPC	5
$\tilde{\varphi}$	deterministic phaseshift	7
$\varphi_m(t)$	base functions for expansion	11
ϕ	azimuth angle of arrival	6, 7
$\eta(t)$	$g(t) * h(t)$	16
κ	auxiliary variable	13
λ, λ_0	wavelength	
λ_{p}	packet transmission rate	17
λ_i	ith eigenvalue	
μ	metric	12
μ	stepwidth of LMS	16
$\mu(t)$	transmission matrix	22
ν	Doppler shift	6
ν_{max}	maximum Doppler shift	7
ν_{m}	mean Doppler shift	5
ν_{F}	Fresnel parameter	5
ω	angular frequency	4

ρ	position vector	
ρ_{km}	correlation coefficients between signals	11
σ_{c}	conductivity	4
σ_{h}	standard deviation of height	4
σ	standard deviation	5
σ_F	standard deviation of local mean	5
σ_{G}	standard deviation of Gaussian pulse	11
σ_{n}	noise standard deviation	
σ_{S}^2	power in symbol sequence	11
τ	delay	4, 5
τ_{Gr}	group delay	5, 12
τ_i	delay of the ith MPC	7
$\tau_{\max}$	maximum excess delay	
$\chi_i(t)$	distortion of the i-th pulse	13
ζ	ACF of $\eta(t)$	16
ξ	SNR loss for discrete precoding	20
$\xi_n(t)$	noise correlation function	12
$\tilde{\xi}_s(t)$	FT of the normalized Doppler spectrum	12
$\xi_s(\nu, \tau)$	scattering function	12
$\xi_h(t, \tau)$	FT of the scattering function	12

Uppercase Greek:

Δh_b	$= h_b - h_{roof}$	7
Δx_s	distance between measurement points	8
$\Delta\tau_{\min}$	minimum resolvable τ	8
Δf_{chip}	difference in chip frequency	8
$\Delta\varphi$	angle difference of paths	4
$\Delta\tau$	runtime difference	5
$\Delta\nu$	Doppler shift	5
Δ	phaseshift between two antenna elements	8
Δ	Lyapunov drift	22
Δ_C	determinant of $\mathbf{C}$	13
$\Delta\phi$	angular range	13
Φ_H	phase of the channel transfer function	5, 12
$\Phi_{\mathrm{CPFSK}}(t)$	phase of transmit signal for CPFSK signal	11
Λ	matrix of eigenvalues	
$\Phi_{\mathrm{TX}}(t)$	phase of transmit signal	
Ω	mean quadratic power Nakagami	5
Ω	direction of departure	
Ω_n	nth moment of Doppler spectrum	5, 13
$\Theta(t)$	queue backlog	22
Θ_e	angle of incidence	4
Θ_r	angle of reflection	4
Θ_t	angle of transmission	4
Θ_n	transmission phase of nth bit	
Θ_{d}	diffraction angle	
ϕ_{TX}	angle TX wedge	4
ϕ_{RX}	angle RX wedge	4
ϕ	azimuth	7
ϕ_0	nominal DOA	7, 13

ϕ_i	DOA of ith wave	13
ψ	auxiliary angle	4, 13
ψ	angle of incidence $90 - \Theta_e$	4
$\bar{x}$	$= E\{x\}$	
$\dot{r}$	$= dr/dt$	
$\mathbf{U}^\dagger$	Hermitian transpose	
$\mathbf{U}^T$	transpose	
$\mathbf{x}^*$	complex conjugate	
Ξ	Fourier transform of ζ_m	
$\mathcal{F}$	Fourier transform	
$\mathcal{X}$	transmit alphabet	14