## Index

3GPP 218

Adaptive techniques 190–192
Adaptive channel coding and modulation 191
Adaptive power control 192
Nulling of weak sub-carriers 191
Advantages and drawbacks of MC-CDMA 49
Advantages and drawbacks of OFDM 34–35
Alamouti space-time block code (STBC) 307
AM/AM (AM/PM) conversion (HPA) 199–200
Analog-to-digital (A/D) conversion 135–136
Antenna diversity 263, 302–330
Antenna gain 209
Automatic gain control (AGC) 154

Bad urban (BA) channel model 20
Beamforming 227
Beyond 3G (B3G) 6, 276
Bit nodes 183–184
BLAST architecture 303–304
Diagonal (D-BLAST) 304
Vertical (V-BLAST) 304
Blind and semi-blind channel estimation 169–170
Block codes 175–178, 180–186
Block linear equalizer 68

Bluetooth 5
Boltzmann constant 209
Broadband (fixed) wireless access (BWA) 50, 238, 242
Channel characteristics 23
Network topology 244
CDMA-2000 3, 42–43
Cellular systems beyond 3G 6, 276
Certification 271
Channel coding and decoding 174–187
Channel estimation 154–174
Adaptive design 159
Autocorrelation function 157
Boosted pilot symbols 161
Cross-correlation function 159
Downlink 170
MC-SS systems 170–174
One-dimensional 159
Overhead due to pilot symbols 161
Performance analysis 162–167, 170–173
Pilot distance 160–161
Robust design 160
Two-dimensional 155–159
Uplink 170
Channel fade statistics 18–19
Channel impulse response 16–17
Channel matrix 34, 57
Channel modeling 16–18
Channel selection in digital domain 334–335
Channel state information (CSI) 190, 207
Channel transfer function 16–17, 25
Check nodes 184
Chips 38, 55
Clock error 143
Code division multiple access (CDMA) 5–6, 36–41, 106
Code division multiplexing (CDM) 106, 186–187
Coding (FEC) for packet transmission 174
CODIT 45
Coherence bandwidth 26
Coherence time 27
Combined equalization 75–76
Common phase error (CPE) correction 196–197
Complexity of FFT 134
Concatenated coding 175–178
Constellation 187–189
Convergence sub-layer 244
Convolutional coding (FEC) 175–180
COST channel models 20–21
Crest factor 60
Cyclic delay diversity (CDD) 227, 311
Cyclic extension 31

Decision directed channel estimation 168–169
Delay diversity 308–309, 314
Delay power density spectrum 17
Delay spread 17–18
Demapping 189–190
Detection techniques 64–71
Multi-user detection 67–71
Single-user detection 64–67
DFT-spread OFDM 116–118, 227–228
Digital AMPS (D-AMPS) 3
Digital audio broadcasting (DAB) 8, 35, 216
Digital signal processor (DSP) 334
Digital-to-analog (D/A) conversion 135–136
Digital video broadcasting (DVB-T) 8, 35, 216, 288
Direct current (DC) sub-carrier 134–135
Direct sequences CDMA (DS-CDMA) 38–42
Receiver 40–41
Transmitter 40
Discontinuous Doppler diversity 313
Discrete Fourier transform (DFT) 31–34, 134
Distributed DFT-spread OFDM 116–118
Diversity 26–28, 301
Diversity in multi-carrier transmission 308–320
Frequency diversity 26, 301
Receive diversity 313–314
Time diversity 27, 301
 Transmit diversity 308–313
Doppler diversity 312–313
Doppler frequency 17–18
Doppler power density spectrum 18
Doppler spread 16, 18
DVB return channel (DVB-RCT) 287–297
Channel characteristics 290
FEC coding and modulation 294–295
Frame structure 292–294
Link budget 296–297
Network topology 288–290
Equal gain combining (EGC) 65–66
Equal gain transmission (EGT) 74, 326
Equalization 64–67, 72–76, 189–190
Euclidean distance 67
EV-DO 4, 42–44
Fast Fourier transform (FFT) 31–32, 133–134
Complexity 134
Field programmable gate array (FPGA) 334
Filter design 159–160
Adaptive 159
Non-adaptive 160
Flexibility with MC-CDMA 81–84
Fourier codes 58–59
Fourier transform 30–32, 133–134
Fourth generation (4G) 6, 219, 276, 301
Frequency diversity 26, 301
Frequency division duplex (FDD) 105–106
Frequency division multiple access (FDMA) 5, 105–106
Frequency division multiplexing (FDM) 105
Frequency error 141–143
Frequency hopping CDMA (FH-CDMA) 38
Frequency hopping OFDMA 111–112
Frequency synchronization 151–154
Coarse frequency synchronization 151–153
CAZAC/M sequence 152
Schmidl and Cox 152–153
Fine frequency synchronization 153–154
Galois field 176
Generalized pre-equalization 76
General packet radio service (GPRS) 2
Generator polynomial 175–176, 181
Global system for mobile communications (GSM) 2–3
Golay code 59
Gold code 59
Guard interval/time 31–32, 56, 133
Hadamard matrix 58
Hamming codes 181
High power amplifier (HPA) models 199–200
Solid state power amplifier (SSPA) 200
Traveling wave tube amplifier (TWTA) 199–200
High speed downlink packet access (HSDPA) 3, 218
High speed packet access (HSPA) 3, 218
High speed uplink packet access (HSUPA) 3, 218
Hilly terrain (HT) channel model 20
HIPERMAN/IEEE802.16 36, 239–263
FEC coding and modulation 262–263
Link budget 272–275
MAC frame structure 247–249
Hybrid multiple access schemes 105–125
Performance comparison 123–125
IEEE 802.11x 5, 8, 35, 284–287
Channel characteristics 283
FEC coding and modulation 285–286
Link budget 287
MAC frame structure 285
Implementation issues 129–210
IMT-2000 1, 3, 45
IMT-Advanced 2, 219
Indoor/outdoor channel models 20–25
Inter-channel interference (ICI) 19
Interference cancellation (IC) 68–71, 81
Interference estimation 206–208
Interleaved FDMA (IFDMA) 116–118
Inter-symbol interference (ISI) 19
Inverse discrete Fourier transform (IDFT) 31–34, 134
Inverse fast Fourier transform (IFFT) 31–34, 134
Inverse OFDM (IOFDM) 29–32
I/Q generation 136–137
Analog quadrature method 136
Digital FIR filtering method 136–137
IS-95 standard 2, 3, 42–44
Joint detection 64
JTC channel model 21
Line of sight (LOS)  16, 18
Link budget  208–210, 272–275, 287, 296–297
Localized DFT-spread OFDM  118, 227–228
Local multipoint distribution system (LMDS)  50
Local oscillator  136–137, 192–201
Log likelihood ratio (LLR)  71, 79–80, 183–185
Interference cancellation  81
Maximum likelihood detection (MLD)  80–81
MC-CDMA  79–81
OFDM  79
Single-user detection  79–80
Long Term Evolution (LTE)  218–237
Cell search  231–232
Medium access control (MAC)  221
MAC scheduler  225
Multi-antenna transmission  226–227, 231
Packet data convergence  221
Performance  235–237
Radio access network (RAN)  220
Radio link control (RLC)  221
Radio resource control (RRC)  220–221
Random access procedure  232
Requirements  219
Resource mapping  223–225, 229–231
Spectrum mask  234
Low density parity check coding (LDPC)  182–186
Bit nodes  183–185
Check nodes  183–184
Tanner graph  183–185
Two steps decoding  186
Low rate convolutional codes  60
LTE channel model  21–23
LTE requirements  219

MAC scheduler  225
Mapping  187–189
Maximum a posteriori (MAP)  67

Maximum likelihood parameter estimation  144–147
Maximum likelihood sequence estimation (MLSE)  67
Maximum likelihood symbol-by-symbol estimation (MLSSE)  68
Maximum ratio combining (MRC)  65, 313–314
Maximum ratio transmission (MRT)  73, 326
MC-CDMA  9–11, 46–49, 55–94
   Downlink signal  56–57
   MC-CDMA software defined radio  335–337
   Performance  84–94
   Spreading  58–60
   Uplink signal  57
MC-DS-CDMA  9–11, 46–49, 94–100
   Downlink signal  96
   Performance  98–100
   Spreading  97
   Uplink signal  96–97
Mean delay  17
Medium access control (MAC)  112, 120, 221, 225, 246–247
Microwave multipoint distribution system (MMDS)  50
Minimum mean square error (MMSE) equalization  66–67
   MMSE block linear equalizer  68
   Quasi MMSE pre-equalization  74
   M-Modification  81–82
   Monocycle  121
   M-QAM constellation  187–189
   M&Q-Modification  83
   Multi band radio  334
   Multi-carrier CDMA (MC-CDMA)  9–11, 46–49, 55–94
   Multi-carrier channel modeling  25–26
   Multi-carrier FDMA (MC-FDMA)  107–118
Multi-carrier modulation and demodulation 130–134
Multi-carrier spread spectrum (MC-SS) 9–11, 46–49, 55–94
Multi-carrier TDMA (MC-TDMA) 118–121
Multi-carrier transmission 28–35
Multi-function radio 335
Multimedia services 215–216
Multipath propagation 15
Multiple access interference (MAI) 41
Multiple input/multiple output (MIMO) 226–227, 231, 263–267, 302–330
MIMO capacity 307
Multiple input/single output (MISO) 303
Multi-role radio 334
Multitone CDMA (MT-CDMA) 96
Multiuser detection 64, 67–71, 97
Narrowband interference rejection 206–208
Noise factor 209
Noise power 208–209
Noise variance 32
Non-linearities 197–206
Effects 197–202
Influence in DS-CDMA 200–201
Influence in MC-CDMA 201–202
High power amplifier (HPA) models 199–200
Pre-distortion techniques 202–205
NTT DOCOMO B3G/4G experiments and field trials 276–282
Null symbol 140, 147, 293
Nyquist pulse shaping 111
Orthogonal frequency division multiplexing (OFDM) 28–36, 130–134
Frame 33, 140
Frame duration 33
Spectrum 30
Standards 35–36
Symbol 30–31, 33
Symbol duration 30–31, 33
Orthogonal frequency division multiple access (OFDMA) 257–261
Code division multiplexing (CDM) 113–116
Frequency hopping OFDMA 111–112
Pulse shaping 110–111
Scalable OFDMA 258–261
Synchronization sensitivity 109–110
Transceiver 112
Output back-off (OBO) 199
Packet data convergence 221
Parallel interference cancellation (PIC) 69–70
Path loss 16, 208–209
Peak-to-average power ratio (PAPR) 60–61, 198
Downlink PAPR 61
Uplink PAPR 60–61
Phase diversity 309–311, 314
Phase lock loop (PLL) 194
Phase noise 193–197
Effects 194–196
Modeling 193–194
Lorenzian power density spectrum 193
Measured power density spectrum 193–194
Pilot symbol grid 155–156
Pre-distortion techniques 202–205
Pre-equalization 72–74
Downlink 72–74
Power constraint 73
Uplink 74
Processing gain 37, 55
One-dimensional channel estimation 159
One-dimensional spreading code 61–62
Orthogonal frequency division multiple access (OFDMA) 107–113,
257–261
Code division multiplexing (CDM) 113–116
Frequency hopping OFDMA 111–112
Pulse shaping 110–111
Scalable OFDMA 258–261
Synchronization sensitivity 109–110
Transceiver 112
Output back-off (OBO) 199
Packet data convergence 221
Parallel interference cancellation (PIC) 69–70
Path loss 16, 208–209
Peak-to-average power ratio (PAPR) 60–61, 198
Downlink PAPR 61
Uplink PAPR 60–61
Phase diversity 309–311, 314
Phase lock loop (PLL) 194
Phase noise 193–197
Effects 194–196
Modeling 193–194
Lorenzian power density spectrum 193
Measured power density spectrum 193–194
Pilot symbol grid 155–156
Pre-distortion techniques 202–205
Pre-equalization 72–74
Downlink 72–74
Power constraint 73
Uplink 74
Processing gain 37, 55
One-dimensional channel estimation 159
One-dimensional spreading code 61–62
Product codes 180–181
Profiles 267–271
Pseudo noise (PN) sequence 37, 55, 59
Pulse position modulation (PPM) 121–123
Pulse shaping 110–111
Punctured convolutional codes 175
QAM constellation 187–189
Quasi MMSE pre-equalization 74
Radio access network (RAN) 220
Radio channel characteristics 15–25
RF issues 192–210
Receiver sensitivity 209
Reed Solomon coding 175–178
Rectangular band-limited transmission filter 132
Rectangular time-limited transmission filter 132
Reed Solomon coding 175–178
Requirements on OFDM frequency and clock accuracy 144
Resource mapping 223–225, 229–231
RF issues 192–210
Rice distribution 19
RMS delay spread 17–18
Rotated constellations 63
Spatial pre-coding 321–331
Spatial diversity 301
Spatial multiplexing 227
Space division multiplexing 106
Space-frequency coding (SFC) 317–321
SSPA characteristics 200
Sub-carrier 29–30
Sparsity 29
Sub-carrier diversity 313
Sub-channel 29
Suboptimum MMSE equalization 66–67
Successive interference cancellation (SIC) 70
Synchronization 138–154
Suboptimum MMSE equalization 66–67
Successive interference cancellation (SIC) 70
Synchronization 138–154
Frequency synchronization 151–154

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum likelihood parameters estimation</td>
<td>144–146</td>
</tr>
<tr>
<td>Time synchronization</td>
<td>147–151</td>
</tr>
<tr>
<td>Synchronization sensitivity</td>
<td>141–143</td>
</tr>
<tr>
<td>System matrix</td>
<td>57</td>
</tr>
<tr>
<td>System performance</td>
<td>84–94, 98–100</td>
</tr>
<tr>
<td>MC-CDMA synchronous downlink</td>
<td>85–89</td>
</tr>
<tr>
<td>MC-CDMA synchronous uplink</td>
<td>89–94</td>
</tr>
<tr>
<td>MC-DS-CDMA asynchronous uplink</td>
<td>98–100</td>
</tr>
<tr>
<td>MC-DS-CDMA synchronous uplink</td>
<td>98</td>
</tr>
<tr>
<td>Tanner graph</td>
<td>183</td>
</tr>
<tr>
<td>TDD frame structure</td>
<td>248–249</td>
</tr>
<tr>
<td>Time diversity</td>
<td>27, 301</td>
</tr>
<tr>
<td>Time division duplex (TDD)</td>
<td>105</td>
</tr>
<tr>
<td>Time division multiple access (TDMA)</td>
<td>5–6, 45, 105</td>
</tr>
<tr>
<td>Time division multiplexing (TDM)</td>
<td>105</td>
</tr>
<tr>
<td>Time domain channel estimation</td>
<td>168</td>
</tr>
<tr>
<td>Time synchronization</td>
<td>147–151</td>
</tr>
<tr>
<td>Coarse symbol timing</td>
<td>147–149</td>
</tr>
<tr>
<td>Guard time exploitation</td>
<td>149</td>
</tr>
<tr>
<td>Null symbol detection</td>
<td>147–148</td>
</tr>
<tr>
<td>Two identical half reference symbols</td>
<td>148–149</td>
</tr>
<tr>
<td>Fine symbol timing</td>
<td>149–150</td>
</tr>
<tr>
<td>Time-variant phase diversity</td>
<td>312</td>
</tr>
<tr>
<td>Total degradation</td>
<td>204</td>
</tr>
<tr>
<td>Transmit diversity in multi-carrier transmission</td>
<td>308–313</td>
</tr>
<tr>
<td>Cyclic delay diversity</td>
<td>311</td>
</tr>
<tr>
<td>Delay diversity</td>
<td>308–309</td>
</tr>
<tr>
<td>Discontinuous Doppler diversity</td>
<td>313</td>
</tr>
<tr>
<td>Doppler diversity</td>
<td>312–313</td>
</tr>
<tr>
<td>Phase diversity</td>
<td>309–311</td>
</tr>
<tr>
<td>Sub-carrier diversity</td>
<td>313</td>
</tr>
<tr>
<td>Time-variant phase diversity</td>
<td>312</td>
</tr>
<tr>
<td>Turbo codes</td>
<td>178–182</td>
</tr>
<tr>
<td>Block Turbo codes</td>
<td>180–182</td>
</tr>
<tr>
<td>Convolutional Turbo codes</td>
<td>178–180</td>
</tr>
<tr>
<td>Two-dimensional channel estimation</td>
<td>155–159</td>
</tr>
<tr>
<td>Two cascaded one-dimensional filters</td>
<td>158–159</td>
</tr>
<tr>
<td>Two-dimensional filter</td>
<td>155–156</td>
</tr>
<tr>
<td>Two-dimensional Wiener filter</td>
<td>156–158</td>
</tr>
<tr>
<td>Two-dimensional spreading</td>
<td>61–62, 278–279</td>
</tr>
<tr>
<td>Two step decoding</td>
<td>186</td>
</tr>
<tr>
<td>TWTA characteristics</td>
<td>199–200</td>
</tr>
<tr>
<td>Typical urban (TU) channel model</td>
<td>20</td>
</tr>
<tr>
<td>Ultra wide band (UWB) systems</td>
<td>121–123</td>
</tr>
<tr>
<td>PPM UWB signal generation</td>
<td>121–123</td>
</tr>
<tr>
<td>Transmission scheme</td>
<td>123</td>
</tr>
<tr>
<td>UMTS standard</td>
<td>3–4, 44–46</td>
</tr>
<tr>
<td>UMTS/UTRA channel model</td>
<td>21</td>
</tr>
<tr>
<td>Uncorrelated fading channel models</td>
<td>26</td>
</tr>
<tr>
<td>Variable spreading factor (VSF)</td>
<td>45, 277–279</td>
</tr>
<tr>
<td>VHF/UHF</td>
<td>290</td>
</tr>
<tr>
<td>Virtual sub-carriers</td>
<td>134–135</td>
</tr>
<tr>
<td>Viterbi decoding</td>
<td>71, 78, 175, 179–180</td>
</tr>
<tr>
<td>VSF-OFCDM</td>
<td>277–279</td>
</tr>
<tr>
<td>Walsh-Hadamard code</td>
<td>58</td>
</tr>
<tr>
<td>Wideband CDMA (WCDMA)</td>
<td>3, 44–46, 218</td>
</tr>
<tr>
<td>WiMAX channel model</td>
<td>23–25</td>
</tr>
<tr>
<td>Wireless Interoperability for Microwave Access (WiMAX)</td>
<td>237–267</td>
</tr>
<tr>
<td>BWA standards</td>
<td>242–263</td>
</tr>
<tr>
<td>Certification</td>
<td>271</td>
</tr>
<tr>
<td>Convergence sub-layer</td>
<td>244–246</td>
</tr>
<tr>
<td>MAC layer</td>
<td>246–253</td>
</tr>
<tr>
<td>MIMO</td>
<td>263–267</td>
</tr>
<tr>
<td>OFDMA</td>
<td>258</td>
</tr>
<tr>
<td>Profiles</td>
<td>267–271</td>
</tr>
<tr>
<td>S-OFDMA</td>
<td>258–261</td>
</tr>
<tr>
<td>Wireless LAN</td>
<td>4–5, 8, 35, 283–287</td>
</tr>
<tr>
<td>Channel characteristics</td>
<td>25, 283</td>
</tr>
<tr>
<td>FEC coding and modulation</td>
<td>285–286</td>
</tr>
<tr>
<td>Link budget</td>
<td>287</td>
</tr>
<tr>
<td>Wireless LAN (continued)</td>
<td>Zadoff-Chu code</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>MAC frame structure 285</td>
<td>Zero forcing (ZF) 66, 68, 74</td>
</tr>
<tr>
<td>Network topology 283</td>
<td>ZF block linear equalizer 68</td>
</tr>
<tr>
<td>Wireless standards 332</td>
<td></td>
</tr>
</tbody>
</table>