

Index

- Alamouti coding
 - comparison with maximal ratio combining, 128–129
 - decoding, 124
 - diversity combining, 119–122
 - encoding, 118–119
 - how to simulate, 127–128
 - performance results, 125–129
 - theoretical analysis, 127
- antenna correlation
 - dependence on antenna spacing, 105–108
 - dependence on scattering angle, 106–107
 - impact on MIMO capacity, 103
- array gain, 7, 60
- augmented OFDM symbol, 204
- average mutual information, 32–33
- BLAST
 - D-BLAST, 135, 164, 166–168
 - H-BLAST, 166
 - V-BLAST, 5, 162, 165–166
- blind-based channel estimation, 214
- breakpoint distance, 73
- channel eigenvalues, 45, 47, 49, 51–52, 54, 164
- channel estimation (CE)
 - classes of techniques, 214
 - least squares estimation, 222
 - LMMSE estimation, 222
 - maximum likelihood estimation, 221
 - narrowband channel estimation, 220–227
 - pilot allocation strategies, 215–220
 - pilot spacing, 217, 219
 - role of pilot tones, 215
 - role of training symbols, 214
 - simulation results, 225–227
 - time-frequency interpolation, 229–230
 - wideband channel estimation, 227–230
- channel impulse response
 - linear time-variant, 75
 - low-pass channel model, 76
 - low-pass equivalent, 75–76
 - two-dimensional nature, 76–77
- channel rank, 16, 44, 45
- channel state information (CSI), 42
- classes of multipath channels, 90–93
- closed loop MIMO, 17–18
- code rate, 132
- coding advantage criterion, 144
- coding gain, 11, 134, 135, 143–145, 157, 158, 160
- coherence bandwidth
 - 50th percentile bandwidth, 84
 - 90th percentile bandwidth, 84
 - definition, 83
 - relation to delay power spectrum, 84
 - relation to delay spread, 84
 - relation to spaced-frequency correlation functions, 84
- coherence time
 - 50th percentile expression, 90
 - definition, 85, 89
 - relation to Doppler spread, 89
- component code, 187
- conditional entropy, 33
- constellation mapper, 239
- CSIR, 42
- CSIT, 42
- cyclic extension, 204
- cyclic prefix, 204
- cyclic shift diversity (CSD), 240, 249
- data streams, 2, 7, 15, 16, 20, 44–45, 58, 162–166, 169, 187, 233–234, 237
- delay power spectrum, 79
- delay spread
 - definition, 78, 80
 - excess delay, 80
 - mean excess delay, 80
 - measured values, 83
 - rms excess delay, 80
- determinant criterion, 144
- direct mapping, 240
- distributed mapping, 256, 257
- diversity
 - diversity combining, 4, 8–11, 115, 118
 - equal gain combining, 9, 10, 135
 - frequency diversity, 8

- maximal ratio combining, 9, 13, 115–117, 127, 129
- polarization diversity, 8
- selective combining, 9
- spatial diversity, 8
- time diversity, 8
- diversity gain, 7, 11, 14, 134–136, 142–144, 166
- diversity order, 7, 11, 14, 114, 116, 128, 183, 184, 194
- diversity-multiplexing tradeoff, 134
- Doppler spectrum
 - Clark's Doppler model, 86
 - definition, 87
 - Doppler model used in IEEE 802.11n, 87
 - general Doppler power spectrum, 89
 - physical cause, 85–87
 - relation to spaced-time correlation function, 89
- Doppler spread
 - definition, 85
 - physical cause, 85–87
- double Rayleigh, 109
- downlink resource grid, 253, 254
- Dreissen, Peter, 4
- eigen-channels, 16, 49
- eigenbeamforming, 15, 18, 42, 47–50
 - eigenmode power allocation, 51–52, 56
 - optimal power allocation, 50–53
 - single-mode, 53–54, 58, 60, 234
- entropy, 30
- equal power allocation, 42, 43
- ergodic capacity
 - definition, 63
 - performance results, 63–64
- ETU (extended typical urban) channel model, 201, 217, 219
- excess delay, 80
- fast fading, 93
- flat fading
 - definition, 90
 - system model under flat fading, 90–91
- Foschini, Gerry, 4, 5
- free space loss, 70, 72–74
- frequency selective fading
 - definition, 91
 - potential capacity improvement, 199–200
 - system equation under F.S. fading, 91–93
 - techniques for mitigating, 198–203
- Friis equation, 72
- Friis, Haraold T., 72
- full-rate space-time codes
 - definition, 133
 - examples, 146–149
- Gray coding, 143
- Greenfield mode, 235–237, 247, 249
- high-capacity criterion, 98
- HT mode, 233, 235
- IEEE 802.11a, 232
- IEEE 802.11a/g, 233–236, 238, 239
- IEEE 802.11n, *see* WiFi
- IEEE 802.11n-2009, 232, 233
- Information
 - definition, 28–30
 - properties of, 29
- interference cancellation
 - with LMMSE, *see* LMMSE-IC
 - with zero forcing, *see* ZF-IC
- interference suppression
 - comparison with interference cancellation, 174
 - in zero forcing, 174
- intrinsic channel parameters, 77
- Iospan, Inc., 5, 18
- Jack Winters, 5
- Kronecker channel model, 101–103
 - advantage of Kronecker model, 103
 - antenna correlation, 103–105
 - relation to practical channels, 101–103
- large-scale fading, 71
- layer mapper, 255–259
- legacy mode, 235–238
- LMMSE, 164, 175–179
- LMMSE-IC, 164, 179–182
- localized mapping, 256, 257
- LOS channel model, 110–111
- LTE
 - data rates, 260–263
 - layer mapper, 255–259
 - OFDM parameter values, 255
 - resource block, 253
 - spatial diversity in, *see* transmit diversity
 - spatial multiplexing in, 259–260
 - transmission blocks (TB), 254
 - transmit diversity in, 257–259
 - transmitter architecture, 255–257
 - waveform description, 253–255
- LTE frame structure, 253
- maximal-ratio receive combining, 115
- maximum likelihood detection, 114, 115, 118
 - as applied in Alamouti decoding, 124
 - definition, 123
- mean excess delay, 80
- MIMO capacity
 - for MISO, 59–60
 - for SIMO, 58–59
 - general expressions, 38–39
 - impact of antenna correlation, 103
 - impact of Rician K-factor, 110

- under CSIR only, 44
 - under optimal channel conditions, 47
- MIMO capacity, definition, 35
- MIMO definition, 1
- MISO, definition of, 3
- mixed mode, 235–237
- MNM, 19–21
- modulation and coding schemes (MCS), 235, 237–239, 251, 252
- Moore–Penrose pseudo inverse, 169
- multi-group space-time coding (MGSTC)
 - decoding, 189–194
 - encoding, 187
 - group-dependent diversity, 193
 - performance, 194–196
- multi-user MIMO, 6, 7
- multipath channels
 - definition, 70
 - phenomenology, 70–72
- multipath intensity profile, 79
- multiple carrier techniques, 201
- mutual Information, 31–32
- noise amplification, 170–171
- normalization, 43, 264–265
- Nyquist–Shannon sampling theorem, 91
- OFDM, 199, 203–209
- OFDM sub-carriers, 202
- OFDM symbol, 204
- OFDMA, 210–211
- open loop MIMO, 17–18
- OSTBC
 - complex, 149, 150
 - computation savings, 152
 - decoding, 150–152, 271–273
 - definition, 146
 - examples, 146–150
 - how to simulate, 153
 - real, non-square, 147
 - real, square, 146
 - simulation performance, 153–155
- outage capacity
 - definition, 65
 - performance results, 66–67
 - theoretical expression for SIMO channel, 65–67
- pair-wise error probability (PEP)
 - definition, 136
 - importance in code design, 136–137
 - relation to decoding error, 142–143
 - upper bounds, 140–142
- path loss exponents, 74
- pilot tone, 215, 218
- pinhole channel, 107–110
- power allocation strategies
 - effect on MIMO performance, 55, 57
 - for CSIR only, 42
 - for CSIR with CSIT, 47
 - for single-mode eigenbeamforming, 53
- power delay profile
 - definition, 79
 - example measurements, 81
- power law propagation, 71–74
- pseudo inverse, *see* Moore–Penrose pseudo inverse
- quasi-OSTBC, 135
- rank criterion, 144
- Rayleigh fading, 93–95
- receive covariance matrix, 101–102
- receive diversity, 4, 9, 19, 20, 114–117, 252, 257
- reflection coefficient, 72–73
- resource block, 253
- Rician fading, 95–96
- Rician K-factor, 96
- rms excess delay, 80
- sampling theorem, 91
- SC-FDMA, 253, 256–257
- shadowing, 71
- Shannon sampling theorem, 91
- Shannon, Claude, 28
- signature vector, 97
- SIMO, definition of, 3
- single carrier techniques, 200
- single-user MIMO, 6, 7
- SISO capacity, definition, 34
- SISO, definition of, 3
- slow fading, 93
- small-scale fading, 71
- smart antennas, 5–6
- space-frequency block coding (SFBC), 211–213
- space-time codeword, 132
- space-time coding
 - Alamouti coding, 118–125
 - design criteria, 144
 - full-rate, 133
 - multi-group space-time codes, 187–195
 - orthogonal space-time block codes, 146–155
 - purpose, 1
 - quasi-OSTBC, 135
 - taxonomy, 134–136
- space-time trellis codes (STTC)
 - comparison with STBCs, 155–156
 - encoding, 156
 - history, 155
 - performance, 157–160
 - spectral efficiency of, 157
- spaced-time correlation function, 89
- spatial diversity, 1–3, 5–9, 11–12, 60, 134–136, 162–169, 183, 187, 211
- spatial expansion, 240
- spatial mapper, 240–242

spatial multiplexing (SM)
 decoding of, 163, 164, 168–181, 189–194
 definition, 2, 15
 maximum data streams, 163
 performance, 181–186, 194–196
 types of, 164
 spatial streams, 239, 243, 251, 256, 259
 spatial white channels, 62
 spectral efficiency, 133
 stream parser, 239, 241
 subcarrier mapper, 256

taxonomy of space-time codes, 134
 Telatar, Emre, 28
 time dispersion, 78
 training symbol, 214, 221, 228–230, 245
 training-based channel estimation, 214
 transmission blocks (TB), 254
 transmit covariance matrix, 101–102
 Transmit diversity
 advantages over receive diversity, 9
 challenges, 9, 11, 117
 definition, 9
 transmit selection diversity, 18
 transport block size (TBS), 261
 two-ray propagation model, 72–74

UE category, 260–263

uncorrelated scattering, 79

waterfilling
 graphical depiction, 52
 relationship to eigenbeamforming, 50
 waterfilling algorithm, 50, 52
 wide sense stationary (WSS), 78, 79
 Wiener filtering, 230
 WiFi, 232–252
 Alamouti coding in, 243
 channel estimation, 247–251
 channel models, 246
 data rates, 251
 MIMO techniques used by, 234
 modulation and coding schemes, 235, 237–239, 251, 252
 OFDM parameter values, 246
 packet structure, 235–237
 space–time coding, 234, 242–244
 spatial diversity in, 241, 242
 spatial multiplexing in, 234, 237, 241–242
 transmit beamforming (TxBF), 234
 transmitter architecture, 237–240
 WSSUS channels, 79

ZF, 2, 164, 168–175
 ZF-IC, 164, 171–175