

Index

Note: Page numbers followed by “*f*” and “*t*” refer to figures and tables, respectively.

A

- Absolute power tolerance, 366
- Access and Mobility Management Function (AMF), 74–75
- Access stratum (AS), 74–75
- ACIR. *See* Adjacent channel interference ratio (ACIR)
- Acknowledged mode (AM), 85, 266–267, 269–273
 - SDU delivery, 272*f*
- ACLR. *See* Adjacent channel leakage ratio (ACLR)
- ACS. *See* Adjacent channel selectivity (ACS)
- Active Antenna System base stations, 389–390
- Active antenna systems (AASs), 358
 - BS requirements, 358–359
 - generalized radio architecture of, 358*f*
- Active downlink bandwidth part, 113–114
- Active uplink bandwidth part, 113–114
- ADCs. *See* Analog-to-Digital Converters (ADCs)
- Additional maximum power reduction (AMPR), 363–365
- Additive white Gaussian noise (AWGN), 391, 408
- Adjacent channel interference ratio (ACIR), 371–372
- Adjacent channel leakage ratio (ACLR), 367, 371–372, 371*f*, 378, 398
- Adjacent channel parameters, 372
- Adjacent channel selectivity (ACS), 354, 371*f*, 372, 375
- Advanced Antenna Systems (A-ASs), 349
- Advanced Mobile Phone System (AMPS), 1
- Advanced multiantenna transmission/reception, 59
- Aerials, 55
- AF. *See* Application Function (AF)
- AGC. *See* Automatic Gain Control (AGC)
- Aggregated power tolerance, 366
- Aggregation level, 188, 195
- Aggregation of spectrum allocations, 352
- Allocations, 352
- Always-on signals, 59–60
- Always-on transmissions, 60
- AM. *See* Acknowledged mode (AM)
- AMF. *See* Access and Mobility Management Function (AMF)
- AMPR. *See* Additional maximum power reduction (AMPR)
- AMPS. *See* Advanced Mobile Phone System (AMPS)
- Analog antenna processing, 243
- Analog beamforming, 63
- Analog front-end, possibilities of filtering at, 399–401
- Analog multiantenna processing, 231
- Analog-to-Digital Converters (ADCs), 390–391
- Analysis, 21
- Antenna, 155–156. *See also* Multiantenna transmission
 - array, 358–359
 - composite, 358–359
 - port fields, 167
 - ports, 128–130, 129*t*, 165
 - selection, 239
- Aperiodic
 - CSI-RS transmission, 140
 - reporting, 147
 - SRS, 151, 242
- Application Function (AF), 75
- Architecture
 - options, 342, 343*f*
 - phase, 22
- Area traffic capacity, 18
- “Around-the-corner” dispersion, 243
- ARQ. *See* Automatic repeat-request (ARQ)
- AS. *See* Access stratum (AS)
- Associated control signaling, 185
- Asynchronous hybrid-ARQ protocol, 93
- Authentication Server Function (AUSF), 75
- Automatic Gain Control (AGC), 405
- Automatic repeat-request (ARQ), 67
- AWGN. *See* Additive white Gaussian noise (AWGN)

B

- Backwards compatibility, 42
- Band categories (BC), 382
- Band-specific device requirements, 363–364
- Bandwidth (BW), 207–209, 401–402
 - adaptation, 62, 280–282, 281*f*
 - of carrier, 354
 - dependencies, 405–411
- Bandwidth parts (BWPs), 61–64, 112–114, 113*f*
- Bandwidth-part indicator (0–2 bit), 204
- Base station (BS), 41, 349
 - classes, 364–365

- Base station (BS) (*Continued*)
 - colocation of BS equipment between operators, 351
 - conducted RF requirements for NR, 357–359
 - control of, 47
 - OBUE limits, 368–370
 - output power and dynamic range, 365
 - radiated RF requirements for NR, 357–359
 - spurious emission, 399
 - structure of BS RF requirements, 357–360
 - conducted and radiated RF requirements for NR BS, 357–359
 - time alignment, 367
 - type 1-C, 359
 - type 1-H, 359–360, 378–379
 - type 1-O, 359–360, 378
 - type 2-O, 359–360
 - types in different FRs for NR, 359–360
 - Base-station dynamic range, 374
 - Baseline power control, 304–306
 - Basic limit, 359–360
 - Basic random-access procedure, 325
 - BC. *See* Band categories (BC)
 - BCCH. *See* Broadcast Control Channel (BCCH)
 - BCH. *See* Broadcast Channel (BCH)
 - Beam adjustment, 245–249
 - beam indication and TCI, 248–249
 - downlink receiver-side, 247, 247f
 - downlink transmitter-side, 245–246, 246f
 - uplink, 247–248
 - Beam correspondence, 243–244
 - Beam establishment during initial access, 332–333
 - Beam failure/recovery, 249–250
 - Beam indication, 248–249
 - Beam management, 231, 243
 - beam adjustment, 245–249
 - beam recovery, 249–252
 - Beam recovery, 249–252
 - beam-failure detection, 250
 - device recovery request and network response, 251–252
 - new-candidate-beam identification, 250–251
 - procedure, 325
 - request, 251–252
 - Beam-based power control, 306–308
 - multiple closed-loop processes, 308
 - multiple open-loop-parameter sets, 307–308
 - multiple path-loss-estimation processes, 306–307
 - use of multiple power-estimation processes, 307f
 - Beam-centric design, 68–69
 - Beam-failure detection, 250
 - Beam-failure events. *See* Beam failure/recovery
 - Beam-failure instance, 250
 - Beam-forming, 55, 68f, 243, 245, 409
 - function, 41
 - for SS block, 317
 - Beam-sweeping
 - for preamble transmission, 332
 - for SS-block transmission, 317
 - Bipolar device, 394–395
 - Bit-level scrambling sequence, 162–163
 - Bitmap-1, 172, 347
 - Bitmap-2, 172
 - Blind decoding, 195–199
 - Blocking, 375
 - Bluetooth, 415
 - Broadcast Channel (BCH), 87, 155
 - Broadcast Control Channel (BCCH), 87, 266
 - BS. *See* Base station (BS)
 - Bucket size duration (BSD), 290
 - Buffer status reports, 292–294
 - BW. *See* Bandwidth (BW)
 - BWPs. *See* Bandwidth parts (BWPs)
- ## C
- C-MTC. *See* Critical machine type communication (C-MTC)
 - C-RNTI. *See* Cell Radio-Network Temporary Identifier (C-RNTI)
 - CA. *See* Carrier aggregation (CA)
 - CACLR. *See* Cumulative ACLR requirement (CACLR)
 - Candidate beams, 250
 - identification, 250
 - Candidate technology, 21
 - Capability set (CS), 382
 - Carrier aggregation (CA), 27–28, 44–45, 44f, 90–91, 90f, 115–118, 119f, 341, 352, 382
 - control signaling, 116–117
 - relation to, 119–120
 - Carrier frequency and mm-wave technology
 - aspects, 408–411
 - Carrier indicator (0 or 3 bit), 204
 - Carrier raster, 70, 316
 - Carrier resource blocks, 168
 - Carrier-selection threshold, 336–337
 - CBG. *See* Code-block group (CBG)
 - CBG Flush Indicator (CBGFI), 259–260
 - CBG transmission indicator (CBGTI), 202, 204, 259–260
 - CBG Transmit Indicator. *See* CBG transmission indicator (CBGTI)
 - CBGFI. *See* CBG Flush Indicator (CBGFI)
 - CBGTI. *See* CBG transmission indicator (CBGTI)

- CCCH. *See* Common control channel (CCCH)
- CCEs. *See* Control channel elements (CCEs)
- cDAI. *See* Counter DAI (cDAI)
- CDM. *See* Code-domain sharing (CDM)
- CDMA-based IS-95 technology, 1–2
- Cell, 116, 336–337
 - group, 84–85
 - reselection, 99
 - system information, 336–337
- Cell Radio-Network Temporary Identifier (C-RNTI), 98–99, 335–336
- Cell search, 313–324
 - details of PSS, SSS, AND PBCH, 319–323
 - frequency-domain position of SS block, 315–316
 - providing remaining system information, 324
 - SS block, 313–315
 - periodicity, 316–317
 - SS burst set, 317–319, 317f
- Cell-specific reference signals (CRS), 40, 134
- CellBarred flag, 322
- Cellular systems, 52–53
- Channel bandwidth (BW_{Channel}), 353–356, 355f, 356f
 - independent, 350
- Channel characteristics of interest, 133
- Channel coding, 157–160, 157f
 - code-block segmentation, 157–158
 - CRC attachment per transport block, 157
 - of PDCCH, 187–188
- “Channel hardening” effect, 277–278
- Channel quality indicator (CQI), 145, 233
- Channel sounding, 133
 - downlink, 134–144
 - basic CSI-RS structure, 134–137, 135f
 - CSI-IM, 140–141
 - CSI-RS resource sets, 142
 - frequency-domain structure of CSI-RS
 - configurations, 137–139
 - mapping to physical antennas, 143–144
 - time-domain property of CSI-RS
 - configurations, 139–140
 - TRS, 142–143, 143f
 - zero-power CSI-RS, 141–142
 - downlink measurements and reporting, 144–147
 - measurement resource, 145–146
 - report quantity, 145
 - report types, 146–147
 - uplink, 147–153
 - mapping to physical antennas, 152–153
 - multiport SRS, 150–151, 150f
 - SRS resource set, 151
 - SRS sequences and Zadoff–Chu sequences, 149–150
 - time-domain structure of SRS, 151
- Channel-dependent scheduling, 66, 91, 277
- Channel-estimation
 - accuracy, 217
 - process, 166
- Channel-state information (CSI), 68, 92, 145, 174, 213
- Channel-state-information for interference
 - measurements (CSI-IM), 140–141
 - alternative structures, 141f
 - resource sets, 142
- Channel-state-information reference signals (CSI-RS), 127, 128f, 133–144, 146, 167, 174, 211, 246, 248, 250. *See also* Sounding reference signals (SRS)
 - basic structure, 134–137, 135f
 - CSI-IM, 140–141
 - density equal to one, 139
 - frequency-domain structure of CSI-RS
 - configurations, 137–139
 - mapping to physical antennas, 143–144
 - periodicity and slot offset, 140f
 - resource sets, 142
 - time-domain property of CSI-RS configurations, 139–140
 - TRS, 142–143, 143f
 - zero-power, 141–142
- Chase combining, 257–258
- Closed-loop
 - power control, 303
 - spatial multiplexing, 41
 - timing control, 326–327
- CMOS, 394–395, 397
- CN. *See* Core Network (CN)
- Co-sited deployments, 341, 342f
- Code-block group (CBG), 67, 94–95, 95f, 158, 257
 - retransmissions, 256f, 257
- Code-block segmentation, 157–158, 158f
- Code-domain sharing (CDM), 135, 136f
 - frequency-domain, 137
 - time/frequency-domain, 137
- Codebook-based beam-forming, 41
- Codebook-based precoding, 167, 240–241
- Codebook-based transmission, 237–240, 239f, 241f
 - single-layer uplink codebooks for case of four antenna ports, 240f
- Coded UL-SCH stream, 225
- Coexistence between operators, 351
 - of TDD systems, 351
- Coexistence with services, 351
- Colocation of BS equipment between operators, 351

- “Comb” structure, 148
- Common control channel (CCCH), 87, 97, 266
- Common resource blocks (CRBs), 110–111, 111*f*, 176
 - grid offset, 323
- Common search spaces, 199
- CoMP. *See* Coordinated multipoint (CoMP)
- Complementary SUL carrier, 336–337
- Component carriers, 44
- Composite antenna, 358–359
- Compression point and gain, 407–408
- Conducted output power level requirements
 - BS output power and dynamic range, 365
 - device output power and dynamic range, 365–366
- Conducted receiver characteristics, 362, 363*t*
- Conducted RF requirements
 - for NR, 360–366
 - band-specific device requirements through network signaling, 363–364
 - BS classes, 364–365
 - conducted output power level requirements, 365–366
 - conducted receiver characteristics, 362
 - conducted transmitter characteristics, 361
 - regional requirements, 362–363
 - for NR BS, 357–359
- Conducted sensitivity, 374
- Conducted transmitter characteristics, 361, 362*t*
- Conducted unwanted emissions requirements, 367–374
 - ACLR, 371–372
 - emission mask in OOB domain, 368–370
 - implementation aspects, 367–368
 - occupied bandwidth, 373
 - spurious emissions, 373
 - transmitter intermodulation, 373–374
- Configurable frequency-domain RACH resource, 327
- Configurable RACH periodicity, 327
- Configured grant type 1, 297
- Configured grant type 2, 298
- Configuring reserved resources, 171, 172*f*
- Connected-state mobility, 102
- Connection density, 19
- Connection management, 97
- Contention
 - contention-free random access, 334
 - resolution, 335
 - resolution and connection set up, 335–336
- Continuous wave signal (CW signal), 375
- Control channel elements (CCEs), 186, 188, 192*f*
- Control channels, 67–68, 86–87
 - structure enhancement, 48
- Control indicator, 267
- Control resource sets (CORESETs), 67, 113, 186, 189–195, 190*f*, 191*f*, 324
 - example of QCL relation for PDCCH beam management, 194*f*
 - normal RS structure and wideband RS structure, 194*f*
- Control signaling, 65–66, 116–117, 120
- Control-plane functions, 74–75
- Control-plane protocols, 97–102. *See also* User-plane protocols
 - connected-state mobility, 102
 - idle-state and inactive-state mobility, 99–102
 - RRC state machine, 97–99, 98*f*
- Control-plane/user-plane split, 74
- Coordinated multipoint (CoMP), 43, 47, 48*f*
 - hypotheses, 48
- Core Network (CN), 73
 - device identifier, 335
- CORESETs. *See* Control resource sets (CORESETs)
- Corporate combiners, 397
- Count value, 276
- Counter DAI (cDAI), 264–265
- CPi. *See* Input compression point (CPi)
- CQI. *See* Channel quality indicator (CQI)
- CRBs. *See* Common resource blocks (CRBs)
- CRC. *See* Cyclic redundancy check (CRC)
- Critical machine type communication (C-MTC), 14–15
- Cross-carrier scheduling, 116, 279, 280*f*
- Cross-scheduling, 116*f*
- CRS. *See* Cell-specific reference signals (CRS)
- CS. *See* Capability set (CS)
- CSI. *See* Channel-state information (CSI)
- CSI-IM. *See* Channel-state-information for interference measurements (CSI-IM)
- CSI-ReportConfig, 144–145
- CSI-RS. *See* Channel-state-information reference signals (CSI-RS)
- Cubic metric, 61–62, 163
- Cumulative ACLR requirement (CACLR), 372
- CW signal. *See* Continuous wave signal (CW signal)
- Cyclic redundancy check (CRC), 256, 323
 - attachment per transport block, 157
 - for error-detecting purposes, 155–156
- Cyclic shift, 151, 215, 328

D

- D-AMPS. *See* Digital AMPS (D-AMPS)
- D2D communication. *See* Device-to-device communication (D2D communication)
- DACs. *See* Digital-to-Analog Converters (DACs)
- DAI. *See* Downlink assignment index (DAI)
- Data
 - allocation, 175
 - indicator, 267
 - radio bearers, 79
 - scrambling identity, 163
 - transmission, 48, 66–67, 287*t*
- DCCH. *See* Dedicated control channel (DCCH)
- DCI. *See* Downlink control information (DCI)
- Decoding, 187–188
- Dedicated control channel (DCCH), 87, 97
- Dedicated Traffic Channel (DTCH), 87
- Demodulation reference signals (DMRSs), 129–130, 165–167, 174, 177*f*, 178*f*, 193, 232, 315
 - for DFT-precoded OFDM uplink, 181–183
 - for OFDM-based downlink and uplink, 175–181, 178*f*, 180*f*
- Dense Urban-eMBB, 21
- Denser reference signal pattern, 193
- Densification, 48–52
- Deployment scenarios, 21, 340–341
- Detailed specification, 23
- Device
 - device-specific search spaces, 197
 - enhancements, 52
 - in-band emissions, 366
 - output power and dynamic range, 365–366
 - recovery request, 251–252
 - RF requirements, structure of, 356–357
 - SEM, 370
 - spurious emission limits, 373
 - transmission of preamble, 324
- Device-to-device communication (D2D communication), 52–53, 53*f*, 417, 418*f*
- Device-to-device discovery, 417
- DFS. *See* Dynamic frequency selection (DFS)
- DFT, 164, 328
- DFT-precoded OFDM, 40, 61, 103–104, 215
 - OFDM uplink, 181–183
- DFT-precoding, 155–156, 163, 164*f*, 221.
 - See also* Multiantenna precoding
- uplink, 164
- Difficult band combinations, 343
- Digital AMPS (D-AMPS), 1–2
- Digital beam-forming, 332
- Digital multiantenna processing, 231
- Digital processing, 229–230
- Digital-to-Analog Converters (DACs), 390–391
- DIGITALEUROPE, 31
- Direct D2D connectivity, 417
- Discontinuous reception (DRX), 87–88, 98–99, 298–302, 301*f*
 - functionality, 300
- Discrete mm-wave filters, 399
- Diverse spectrum allocations, 350
- DL-SCH. *See* Downlink Shared Channel (DL-SCH)
- DMRSs. *See* Demodulation reference signals (DMRSs)
- Donor cell, 49
- Double-symbol reference signal, 179–181
- Downlink, 155, 185–212, 418. *See also* Uplink
 - beam, 332
 - blind decoding and search spaces, 195–199
 - channel-dependent scheduling, 92
 - control channels, 67
 - control resource set, 189–195
 - control signaling, 185
 - downlink scheduling assignments, 199–202
 - hybrid-ARQ, 259–260
 - interference scenario, 50
 - L1/L2 control signaling, 168, 185
 - measurements and reporting, 144–147
 - measurement resource, 145–146
 - report quantity, 145
 - report types, 146–147
 - multiantenna transmission, 128
 - PDCCH, 186–189
 - precoding, 165–166, 165*f*
 - preemption handling, 282–283
 - preemption indication, 205
 - receiver-side beam adjustment, 247, 247*f*
 - reserved resources, 168, 171–173
 - scheduler, 91, 278
 - scheduling, 91
 - assignments, 199–202
 - signaling
 - of frequency-domain resources, 206–209
 - of time-domain resources, 209–211
 - of transport-block sizes, 211–212
 - slot, 216–217
 - format indication, 205
 - spatial multiplexing, 46
 - SRS control commands, 206
 - symbols, 126
 - time–frequency grid, 174
 - transmissions, 243, 308–309
 - direction, 230–231
 - suitable transmitter/receiver beam pair for, 243–244

- Downlink (*Continued*)
 - transmitter-side beam adjustment, 245–246, 246f
 - uplink power control commands, 206
 - uplink scheduling grants, 202–205
 - Downlink assignment index (DAI), 202, 204, 264–265
 - Downlink channel sounding, 134–144. *See also* Uplink channel sounding
 - basic CSI-RS structure, 134–137, 135f
 - CSI-IM, 140–141
 - CSI-RS resource sets, 142
 - frequency-domain structure of CSI-RS configurations, 137–139
 - mapping to physical antennas, 143–144
 - time-domain property of CSI-RS configurations, 139–140
 - TRS, 142–143, 143f
 - zero-power CSI-RS, 141–142
 - Downlink control information (DCI), 96, 186, 200, 255–256
 - format 0–0, 202–205, 203t
 - format 0–1, 202–205, 203t
 - format 2–0, 205
 - format 2–1, 205
 - format 2–2, 206
 - format 2–3, 206
 - formats 1–0 and 1–1, 199–202, 201t
 - scheduling assignment in, 259
 - Downlink multiantenna precoding, 232–237. *See also* NR uplink multiantenna precoding
 - type I CSI, 234–236
 - type II CSI, 236–237
 - Downlink Shared Channel (DL-SCH), 88, 155
 - Downlink/uplink (DL/UL)
 - carrier pair, 117
 - reference configurations, 344
 - DR. *See* Dynamic range (DR)
 - DRX. *See* Discontinuous reception (DRX)
 - DTCH. *See* Dedicated Traffic Channel (DTCH)
 - Dual connectivity, 50, 51f, 78, 84, 90–91
 - with split bearer, 84f
 - Dual-band base stations, 383
 - Duplex filters, 123
 - Duplex flexibility, 418–419
 - full duplex on link level vs. cell level, 419f
 - Duplex schemes, 64–65, 64f, 121–128, 122f
 - FDD, 123–124
 - slot format and slot-format indication, 124–128, 125f
 - TDD, 121–123
 - variation of, 351
 - Duplication functionality, 275
 - Dynamic activation/deactivation, 173f
 - in case of multiple configured resource sets, 173f
 - of rate-matching resource set, 172–173
 - Dynamic downlink scheduling, 277–283. *See also* Dynamic uplink scheduling
 - bandwidth adaptation, 280–282, 281f
 - downlink preemption handling, 282–283
 - Dynamic frequency selection (DFS), 415–416
 - Dynamic Point Selection, 47–48
 - Dynamic range (DR), 374, 405, 408
 - BS output power and, 365
 - device output power and, 365–366
 - reference sensitivity and, 378
 - requirements, 362
 - Dynamic scheduling, 67, 91–92, 277, 282, 297
 - Dynamic TDD, 50–51, 64–65, 121–122, 125, 296–297, 418
 - Dynamic uplink scheduling, 283–296. *See also* Dynamic downlink scheduling
 - buffer status reports, 292–294
 - downlink preemption indication, 284f
 - power headroom reports, 294–296, 296f
 - scheduling request, 290–292, 293f
 - uplink priority handling, 288–290
- ## E
- Effective isotropic radiated power (EIRP), 377
 - Efficient mobility handling, 99
 - Eight-port CSI-RS, 137, 138f
 - eIMTA. *See* Enhanced Interference Mitigation and Traffic Adaptation (eIMTA)
 - EIRP. *See* Effective isotropic radiated power (EIRP)
 - EIS. *See* Equivalent isotropic sensitivity (EIS)
 - Electrical breakdown voltage (E_{br}), 409
 - Electromagnetic fields (EMFs), 36
 - eMBB. *See* Enhanced Mobile Broadband (eMBB)
 - EMFs. *See* Electromagnetic fields (EMFs)
 - Emission
 - mask in OOB domain, 368–370
 - BS OBUE limits, 368–370
 - device SEM, 370
 - unwanted emission
 - limits, 362
 - requirements, 361
 - Enhanced Interference Mitigation and Traffic Adaptation (eIMTA), 51
 - Enhanced Mobile Broadband (eMBB), 4, 11–12, 14, 57
 - EPC. *See* Evolved Packet Core (EPC)
 - Equivalent isotropic sensitivity (EIS), 378–379
 - Error vector magnitude (EVM), 354, 366

- European Telecommunications Standards Institute (ETSI), 3
- Evaluation configurations, 21
- Evaluation guideline, 13
- EVM. *See* Error vector magnitude (EVM)
- Evolved Packet Core (EPC), 39, 57, 73
- Explicit mapping, 79
- Extended multiantenna transmission, 46–47
- Extended Zadoff–Chu sequence, 150

- F**
- Factory automation, 417
- Fallback format. *See* Downlink control information (DCI)—format 0–0
- Fast hybrid ARQ with soft combining, 41
- FCC. *See* Federal Communications Commission (FCC)
- FDD. *See* Frequency-division duplex (FDD)
- Full-duplex-capable device (FDD)
- FDD–TDD aggregation, 45
- FDM. *See* Frequency domain sharing (FDM)
- FE. *See* Front End (FE)
- FEC. *See* Forward Error Correction (FEC)
- Federal Communications Commission (FCC), 36
- Fifth-generation (5G), 3
 - first release
 - D2D communication, 417, 418*f*
 - integrated access-backhaul, 413–414
 - machine-type communication, 416–417
 - nonorthogonal access, 416
 - operation in unlicensed spectra, 415–416
 - spectrum and duplex flexibility, 418–419
 - 3GPP and standardization of mobile communication, 2–3
 - 5G Americas, 8
 - 5G/NR, 3–6, 395
 - 5G use cases, 4, 4*f*
 - 5GCN, 6
 - evolution of LTE and NR, 6*f*
 - evolving LTE to 5G capability, 5
 - radio-access technology, 5–6
 - standardization, 7
 - 3GPP standardization, 22–26
 - 5G and IMT-2020, 14–21
 - ITU-R activities from 3G to 5G, 9–14
 - and regulation, 7–8
- Figure-of-Merit (FoM), 390–391
- Filtering, 367–368, 398–404
 - filter implementation examples, 402–404
 - LTCC filter implementation example, 404
 - PCB integrated implementation example, 402–404
 - IL and bandwidth, 401–402
 - possibilities of filtering at analog front-end, 399–401
 - filter example for 28 GHz band, 400*f*
 - possible filter locations, 400*f*
- First generation
 - of mobile communication, 1
 - NMT technology, 3
- 1st PDSCH DMRS position, 323
- 5G core network (5GCN), 6, 73–76
- Flexible OFDM-based physical layer, 360–361
- “Flexible” symbols, 126
- FoM. *See* Figure-of-Merit (FoM)
- Forward compatibility, 60–61
- Forward Error Correction (FEC), 253
- Four-step random-access procedure, 324–325, 325*f*
- Fourth-generation (4G), 2. *See also* Long-Term Evolution (LTE)
 - mobile communication, 389
- FPLMTS. *See* Future Public Land Mobile Systems (FPLMTS)
- Fractional path-loss compensation, 303, 305
- Fragmented spectra, 44
- Frames, 106–107, 107*f*
 - structure, 61–64
- Free-running oscillators, PN characteristics of, 392–393
- Frequency
 - error, 366
 - hopping, 221
 - multiplex beam-formed transmissions, 230–231
 - offset, 366
- Frequency bands, 27
 - frequency-band-dependent, 123–124
 - for NR, 32–36
 - release-independent frequency-band principles, 351–352
- Frequency domain sharing (FDM), 135
- Frequency ranges (FRs), 32–33, 352–353, 352*t*, 353*f*, 367, 369*f*, 370*f*
 - FR1, 33, 62
 - radiated base-station requirements in, 378–379
 - FR2, 33, 62, 389
 - radiated base-station requirements in, 379–380
 - radiated device requirements in, 377–378
 - for NR BS types in, 359–360
 - RF requirements in, 352–353
- Frequency-division duplex (FDD), 1–2, 27–28, 39, 64, 121, 123–124, 260–261, 418
- Frequency-domain, 166, 193
 - CDM, 137
 - location of NR carriers, 114–115

Frequency-domain (*Continued*)
 position of SS block, 315–316
 resource
 allocation, 204
 resource-block allocation types, 208*f*
 signaling, 206–209
 structure, 109–112
 of CSI-RS configurations, 137–139
 Frequency-hopping flag (0 or 1 bit), 204
 Friis' formula, 406
 Front End (FE), 405
 Front-loaded reference signals, 65–66, 175–176
 FRs. *See* Frequency ranges (FRs)
 Full coherence, 238
 Full duplex, 419
 on link level vs. cell level, 419*f*
 Full-dimension MIMO, 46
 Full-duplex operation, 123–125
 Full-duplex-capable device (FDD), 126
 Fundamental bandwidth of NR carrier, 354
 Future Public Land Mobile Systems (FPLMTS),
 10

G

5G. *See* Fifth-generation (5G)
 5GCN. *See* 5G core network (5GCN)
 Gain, compression point and, 407–408
 Gallium arsenide (GaAs), 397
 Gallium nitride (GaN), 397
 FET structures, 394–395
 technology, 397
 Global mobile Suppliers Association (GSA), 31
 Global spectrum situation for 5G, 31–32
 Global System for Mobile communication (GSM),
 1–2, 383
 gNB, 76–77, 263–264, 283
 distributed units (gNB-DU), 77
 central unit (gNB-CU), 77
 gNB-DU. *See* gNB distributed units (gNB-DU)
 Gold sequence, 176
 3GPP. *See* Third-Generation Partnership Project
 (3GPP)
 Group index, 182–183
 GSA. *See* Global mobile Suppliers Association
 (GSA)
 GSM. *See* Global System for Mobile
 communication (GSM)
 GSM Association (GSMA), 8
 Guard period. *See* Guard time
 Guard time, 122–123, 123*f*, 326, 326*f*

H

Half-duplex

FDD, 121
 operation, 123–124
 Half-frame bit, 321, 323
 Harmonized standards, 8
 HARQ. *See* Hybrid Automatic Repeat Request
 (HARQ)
 HBTs, 394–395
 Header compression, 273–275
 Heterogeneous deployments, 48–52, 50*f*
 High Electron Mobility Transistor (HEMT),
 394–395
 High Speed Packet Access (HSPA), 1–2, 277
 Higher SNR transmission scheme, 374
 Higher-frequency
 bands, 32, 318, 321, 415–416
 operation, 59
 Higher-layer protocols, 66
 HSPA. *See* High Speed Packet Access (HSPA)
 Hybrid Automatic Repeat Request (HARQ), 67,
 253, 336
 acknowledgments, 212, 216*f*, 262–265,
 308–309
 hybrid-ARQ-related information, 202, 204
 mechanism, 257, 260, 297
 protocol, 254
 retransmission, 257, 300
 with soft combining, 93–95, 254–265
 downlink, 259–260
 dynamic hybrid-ARQ acknowledgment
 codebook, 265*f*
 multiplexing of hybrid-ARQ
 acknowledgments, 262–265
 semistatic hybrid-ARQ acknowledgment
 codebook, 263*f*
 soft combining, 257–259
 timing of uplink acknowledgments, 260–262,
 261*f*
 uplink, 260
 Hybrid-ARQ. *See* Hybrid Automatic Repeat
 Request (HARQ)
 “Hybrid” set, 359, 378–379
 Hypothetical error rate, 250

I

ICIC. *See* Inter-Cell Interference Coordination
 (ICIC)
 ICNIRP. *See* International Commission on Non-
 Ionizing Radiation (ICNIRP)
 ICS. *See* In-channel selectivity (ICS)
 Identity of logical channel (LCID), 89
 Idle-state mobility, 99–102
 paging message transmission, 101–102
 tracking device, 100–101

- III–V materials, 397
 - IL. *See* Insertion loss (IL)
 - IMD. *See* Intermodulation distortion (IMD)
 - IMT system. *See* International Mobile Telecommunications system (IMT system)
 - In-channel selectivity (ICS), 364, 375
 - Inactive-state mobility, 99–102
 - paging message transmission, 101–102
 - tracking device, 100–101
 - Inband relaying, 414
 - Incremental redundancy (IR), 257, 258*f*
 - Independent channel bandwidth definitions, 350
 - Indoor Hotspot-eMBB, 21
 - Industry forums, 8
 - Initial access, 70–71, 313
 - association between SS-block time indices and RACH occasions assuming, 333*f*
 - beam establishment during, 332–333
 - cell search, 313–324
 - random access, 324–337
 - Initial beam establishment, 244–245
 - Input compression point (CPI), 407
 - Insertion loss (IL), 401–402, 405, 407
 - Integrated access-backhaul, 413–414
 - wireless backhaul vs. access link, 414*f*
 - Integrated circuit technology, 391, 395–397
 - Intelligent transportation systems (ITSs), 54
 - Inter-Cell Interference Coordination (ICIC), 47
 - Interband aggregation, 115
 - Interference
 - avoidance by spatial separation, 68
 - interference-mitigation techniques, 55
 - suppression/cancellation, 419
 - Interfering signals
 - leakage, 371–372
 - receiver susceptibility to, 362, 374–376
 - Interleaved case, 191
 - Interleaved mapping, 168
 - Interleaved VRB-to-PRB mapping, 170
 - Intermodulation distortion (IMD), 342–343
 - International Commission on Non-Ionizing Radiation (ICNIRP), 36
 - International Mobile Telecommunications system (IMT system), 9–10
 - IMT-2000, 10–11, 11*f*
 - core band, 28
 - IMT-2020, 14–21
 - capabilities, 16–19
 - minimum technical performance requirements for, 20*r*
 - performance requirements and evaluation, 19–21
 - process in ITU-R WP5D, 11–14, 13*f*
 - usage scenarios for, 14–16
 - use cases and mapping to usage scenarios, 15*f*
 - IMT-Advanced, 10–11, 11*f*, 12*f*
 - spectrum defined for, 28–31
 - technologies, 351
 - International RF EMF exposure limits, 36
 - International Technology Roadmap for Semiconductors (ITRS), 408–409
 - International Telecommunications Union (ITU), 8.
 - See also* ITU Radio Regulations (ITU-R)
 - Interworking, 71–72
 - Intra-frequency-reselection flag, 322
 - Intraband
 - aggregation, 115
 - noncontiguous carrier aggregation, 386
 - IP3. *See* Third-order intercept point (IP3)
 - IR. *See* Incremental redundancy (IR)
 - ITRS. *See* International Technology Roadmap for Semiconductors (ITRS)
 - ITSs. *See* Intelligent transportation systems (ITSs)
 - ITU. *See* International Telecommunications Union (ITU)
 - ITU Radio Regulations (ITU-R), 16, 28, 30, 367
 - activities from 3G to 5G, 9–14
 - IMT-2000, 10–11
 - IMT-2020 process in ITU-R WP5D, 11–14
 - IMT-ADVANCED, 10–11
 - role of ITU-R, 9–10
 - relation between key capabilities and three usage scenarios, 17*f*
 - spectrum defined for IMT systems by, 28–31
- J**
- Johnson limit, 395–397, 409
 - Joint Transmission, 47–48
- K**
- Key capabilities, 19
 - of IMT-2020, 16, 16*f*
 - relation between key capabilities and usage scenarios of ITU-R, 17*f*
 - Key performance indicator (KPI), 17
 - Knee-voltage, 397
- L**
- L1-RSRP, 145, 246, 250–251
 - L1/L2 control
 - channels, 334
 - signaling, 185
 - LAA. *See* License-assisted access (LAA)
 - Latency, 18
 - latency-wise LTE, 41
 - reduction, 54
 - Layer mapping, 163

- LBT. *See* Listen-before-talk (LBT)
 - LCID. *See* Identity of logical channel (LCID)
 - LDPC. *See* Low-density parity-check (LDPC)
 - Leeson formula, 392–393, 392*f*
 - License-assisted access (LAA), 43, 45–46, 46*f*, 415–416, 416*f*
 - Licensed spectra, 415
 - Licensed spectrum, 45–46
 - Limited-buffer rate matching, 161, 162*f*
 - Linear multiantenna transmission, 229
 - Listen-before-talk (LBT), 415–416
 - procedure, 63
 - LNA. *See* Low-noise Amplifier (LNA)
 - LO. *See* Local Oscillator (LO)
 - Local area BS, 364
 - Local Oscillator (LO), 391
 - generation, 391–395
 - Logical channel(s), 82, 86–91
 - groups, 292–294
 - multiple, 288
 - multiplexing, 285
 - Logical node, 76–77
 - Long preambles, 328–332
 - number of RACH time-domain occasions, 331*t*
 - preamble formats for, 330*t*
 - short preambles, 331*t*
 - Long PUCCH formats, 214–215
 - Long-Term Evolution (LTE), 39, 73, 109, 227, 260–261, 279, 315–317, 324–325, 354, 416–417. *See also* LTE/NR; New Radio (NR)
 - bands, 353
 - coexistence, 71–72
 - CRS, 134, 346
 - densification, 48–52
 - design, 60
 - device enhancements, 52
 - dual connectivity, 50, 51*f*
 - dynamic TDD, 50–51
 - and evolution, 40*f*, 42–43, 42*f*
 - heterogeneous deployments, 48–52
 - LTE-based technologies, 57
 - multiantenna enhancements, 46–48
 - new scenarios, 52–55
 - aerials, 55
 - device-to-device communication, 52–53, 53*f*
 - latency reduction, 54
 - MTC, 53–54
 - V2V, 54–55, 55*f*
 - V2X, 54–55, 55*f*
 - PBCH, 346
 - PSS and SSS, 346–347
 - re-farming bands, 33
 - release 8, 39–42
 - release-8/9 devices, 49
 - release 9, 42
 - release 10, 42, 44–45
 - release 11, 43, 45
 - release 12, 43, 45
 - release 13, 43, 45
 - release 14, 43
 - release 15, 43
 - small cells, 48–52
 - spectrum flexibility, 43–46
 - technology, 2
 - WLAN interworking, 51–52
 - Longer SS-block periodicity, 317
 - Low-density parity-check (LDPC), 66
 - coder in NR, 157
 - codes, 158–159, 159*f*
 - Low-frequency bands, 31
 - Low-latency support, 65–66
 - Low-noise Amplifier (LNA), 405
 - Low-SNR transmission scheme, 374
 - Low-Temperature Cofired Ceramics (LTCC), 404
 - filter implementation example, 404
 - Lower-frequency bands, 71, 321, 344
 - LTCC. *See* Low-Temperature Cofired Ceramics (LTCC)
 - LTE. *See* Long-Term Evolution (LTE)
 - “LTE CORESET”, 189
 - LTE-Advanced, 24
 - LTE-Advanced Pro, 24, 43
 - LTE/NR. *See also* Long-Term Evolution (LTE)
 - coexistence, 344–348, 345*f*, 350
 - configuration of reserved resource, 347*f*
 - downlink/uplink coexistence vs. uplink-only coexistence, 346*f*
 - dual-connectivity, 340–344, 340*f*
 - architecture options, 342, 343*f*
 - deployment scenarios, 340–341
 - in multilayer scenario, 341*f*
 - single-TX operation, 342–344
 - interworking, 339–340
 - migration of LTE spectrum to NR, 345*f*
 - spectrum coexistence, 71
- ## M
- M*-sequence, 320–321, 320*f*
 - MAC. *See* Medium-Access Control (MAC)
 - MAC control elements (MAC CE), 89–90, 117, 139–140, 292
 - for buffer status reporting and power headroom reports, 294*f*
 - Machine-type communication (MTC), 53–54, 416–417
 - Macrocell, 364

- Mapping to physical antennas
 - CSI-RS, 143–144
 - SRS, 152–153
- Massive Machine-Type Communication (mMTC), 4, 11–12, 15, 57, 416–417
- Massive MIMO, 68
- Master Cell Group (MCG), 84, 310
- Master Information Block (MIB), 87, 189, 321, 323
- Master node, 340
- Maximum power reduction (MPR), 365
- MCG. *See* Master Cell Group (MCG)
- Medium range BS, 364
- Medium-Access Control (MAC), 66, 82, 86–95, 268*f*
 - hybrid ARQ with soft combining, 93–95
 - layer, 155
 - logical channels and transport channels, 86–91
 - multiplexing functionality, 288
 - protocol layers, 253–254
 - scheduling, 91–93
- Medium-frequency bands, 31
- MIB. *See* Master Information Block (MIB)
- Microcell, 364
- Millimeter-wave Los, 394
- MIMO, 39–40
 - distributed, 69
 - full-dimension, 46
 - massive MIMO implementation, 29
- “Mini-slot” transmission, 62–63, 65–66, 107–108
- Minimum processing time
 - in OFDM symbols from grant reception to data transmission, 287*t*
 - PDSCH mapping type A, feedback on PUCCH, 262*t*
- mm-wave domain, operation in, 63
- mm-wave frequencies, 389, 397
 - RF technologies at
 - ADC and DAC considerations, 390–391
 - filtering, 398–404
 - LO generation and phase noise aspects, 391–395
 - PA efficiency in relation to unwanted emission, 395–398
 - receiver noise figure, DR, and bandwidth dependencies, 405–411
- mm-wave signal generation, challenges with, 393–395
- mm-wave technology, 377–378
- mMTC. *See* Massive Machine-Type Communication (mMTC)
- Mobile communication. *See also* International Telecommunications Union (ITU)
 - 3GPP and standardization, 2–3
 - generations, 2*f*
 - first, 1
 - second, 1–2
 - third, 1–2
 - system, 227–228
- Mobile services, 30
- Mobile systems
 - operators, 352
 - spectrum for, 27–32
- Mobility, 18–19
- Modern high-speed CMOS devices, 409
- Modulation, 163
 - symbol, 162
- Monolithic VCO implementation, 394
- Monte Carlo analysis, 403
- Moore’s law, 395–397, 409
- MPR. *See* Maximum power reduction (MPR)
- MSR. *See* Multistandard radio (MSR)
- MTC. *See* Machine-type communication (MTC)
- MU-MIMO. *See* Multiuser MIMO (MU-MIMO)
- Multi-RAT-capable MB-MSR base station, 383
- Multi-SRS transmission, 239–240
- Multiantenna
 - multiantenna-related information, 202, 204–205
 - processing, 229
 - schemes, 41
- Multiantenna enhancements, 46–48
 - control channel structure enhancement, 48
 - transmission
 - extended multiantenna, 46–47
 - multipoint coordination and, 47–48
- Multiantenna precoding, 128, 164–167, 231, 243.
 - See also* DFT-precoding
 - downlink precoding, 165–166
 - uplink precoding, 167
- Multiantenna transmission, 68–69, 227
 - analog multiantenna processing providing beam forming, 230*f*
 - analog vs. digital multiantenna processing, 230*f*
 - DMRS precoded, 232*f*
 - downlink multiantenna precoding, 232–237
 - general model of multiantenna transmission mapping, 230*f*
 - multiantenna transmission/reception, 227
 - NR uplink multiantenna precoding, 237–242
 - simultaneous (frequency-multiplexed) beam-forming, 232*f*
 - time-domain (nonsimultaneous) beam-forming, 231*f*

- Multiband-capable base stations, 382–385
- Multilayer transmission, 163
- Multinational basis, 3
- Multipanel CSI, 236, 237*f*
- Multiple antennas, 227
- Multiple closed-loop processes, 308
- Multiple compression algorithms, 273–275
- Multiple hybrid-ARQ processes, 255, 255*f*
- Multiple open-loop-parameter sets, 307–308
- Multiple orthogonal reference signals, 176
- Multiple parallel hybrid-ARQ processes, 94, 94*f*
- Multiple path-loss-estimation processes, 306–307
- Multiple periodic NZP-CSI-RS, 142
- Multiple RATs, 380
- Multiple uplink carriers, power control in case of, 309–310
- Multiplexing capacity, 179
- Multiplexing of hybrid-ARQ acknowledgments, 262–265
- Multipoint
 - coordination, 47–48
 - reception, 48
 - transmission, 47–48
- Multipoint
 - CSI-RS, 135
 - SRS, 150–151, 150*f*
- Multistandard radio (MSR), 380
 - base station, 380–382
- Multiuser diversity, 277
- Multiuser MIMO (MU-MIMO), 233–234

N

- NAICS. *See* Network-assisted interference cancellation (NAICS)
- Name slot format, 125
- Narrow-band Internet-of-Things (NB-IoT), 54, 416–417
- Narrowband blocking, 375
- Narrowband intermodulation, 375
- NAS. *See* Non-Access Stratum (NAS)
- N_AX1 precoder vector, 41
- NB-IoT. *See* Narrow-band Internet-of-Things (NB-IoT)
- NEF. *See* Network Exposure Function (NEF)
- Neighboring subcarriers, 179
- Network, 197, 326
 - energy efficiency, 18
 - network-side beam-sweeping, 71
 - response, 251–252
 - slicing, 74
 - transmission of RAR, 324–325
- Network Exposure Function (NEF), 75

- Network signaling, 362–363
 - band-specific device requirements through, 363–364
- Network-assisted interference cancellation (NAICS), 52
- New bands, 27–28
- New Radio (NR), 5–6, 57–58, 73, 104, 253–256, 277, 296, 313, 324–325, 328–330, 349–351, 413–414. *See also* Long-Term Evolution (LTE)
 - antenna ports, 129*t*
 - bands, 352
 - beamforming, 68*f*
 - BS types in different FRs, 359–360
 - carrier, 341
 - frequency-domain location, 114–115
 - fundamental bandwidth, 354
 - raster, 115*f*
 - conducted RF requirements, 360–366
 - band-specific device requirements through network signaling, 363–364
 - BS classes, 364–365
 - conducted output power level requirements, 365–366
 - conducted receiver characteristics, 362
 - conducted transmitter characteristics, 361
 - regional requirements, 362–363
- control channels, 67–68
- CSI-RS in, 134–135
- developments of RF requirements, 380–387
- device, 144–145, 350
- downlink
 - physical channels, 232–233
 - transmissions, 314–315
 - and uplink scheduling, 286*f*
- duplex schemes, 64–65, 64*f*
- forward compatibility, 60–61
- frequency bands for, 32–36
- 3GPP timeline, 58*f*
- higher-frequency operation and spectrum flexibility, 59
- hybrid-ARQ protocol, 186
- initial access, 70–71, 332
- interworking and LTE coexistence, 71–72
- low-latency support, 65–66
- NR BS
 - conducted RF requirements, 357–359
 - radiated RF requirements, 357–359
- NR–LTE coexistence, 72*f*
- radiated RF requirements for, 377–380
- release 15, 413
- resource block, 109

- specifications, 172, 199
 - spectra identified for NR and corresponding
 - subcarrier spacings, 62^f
 - subcarrier spacings supported by, 105^t
 - time-domain structure, 62–63
 - transmission
 - beam-centric design and multiantenna, 68–69
 - scheduling and data, 66–67
 - scheme, bandwidth parts, and frame structure, 61–64
 - timing of NR uplink transmissions, 326
 - ultralean design, 59–60
 - uplink power control, 303–304
 - New-candidate-beam identification, 250–251
 - New-data indicator, 259
 - Next Generation Mobile Networks (NGMN), 8
 - NG control-plane part (NG-c), 77
 - NG interface, 77
 - NG user-plane part (NG-u), 77
 - NG-c. *See* NG control-plane part (NG-c)
 - ng-eNB, 76–77
 - NG-RAN, 76
 - NG-u. *See* NG user-plane part (NG-u)
 - NGMN. *See* Next Generation Mobile Networks (NGMN)
 - NMT. *See* Nordic Mobile Telephony (NMT)
 - No coherence, 238
 - Noise
 - factor and noise floor, 406–407
 - figure, 374
 - NOMA. *See* Nonorthogonal multiple access (NOMA)
 - Non-Access Stratum (NAS), 74–75
 - control-plane functionality, 97
 - Registration Update, 101
 - Non-DFT-precoded OFDM, 61
 - Non-LTE technologies, 413
 - Noncodebook-based precoding, 167, 241–242, 242^f
 - Noncodebook-based transmission, 237
 - Noncontiguous spectra, operation in, 386–387, 386^f
 - Noninterleaved mapping, 191
 - Nonorthogonal access, 416
 - Nonorthogonal multiple access (NOMA), 416
 - Nonstandalone (NSA), 357
 - mode, 6
 - operation, 75
 - Nonzero-power CSI-RS (NZP-CSI-RS), 141–142
 - multiple periodic, 142
 - Nordic Mobile Telephony (NMT), 1
 - Normalized target received power, 305
 - NR. *See* New Radio (NR)
 - NR Repository Function (NRF), 75
 - NR uplink multiantenna precoding, 237–242.
 - See also* Downlink multiantenna precoding
 - codebook-based transmission, 238–240
 - noncodebook-based precoding, 241–242
 - NR-based Access to Unlicensed Spectrum*, 415
 - NRF. *See* NR Repository Function (NRF)
 - NSA. *See* Nonstandalone (NSA)
 - Numerologies, 315
 - multiple and mixed, 350
 - numerology-independent time reference, 107
 - 240 kHz numerology, 315
 - Nyquist sampling frequency, 390–391
 - NZP-CSI-RS. *See* Nonzero-power CSI-RS (NZP-CSI-RS)
 - NZP-CSI-RS-ResourceSets, 142, 145
- ## O
- OBUEs. *See* Operating band unwanted emissions (OBUEs)
 - Occupied bandwidth, 373
 - OFDM. *See* Orthogonal frequency-division multiplexing (OFDM)
 - OOB. *See* Out-of-band (OOB)
 - OOB blocking. *See* Outside operating band (OOB blocking)
 - Open-loop parameters, 307–308
 - pairs, 308
 - Open-loop power control, 303
 - Operating band unwanted emissions (OBUEs), 368
 - BS OBUE limits, 368–370
 - Operating bands, 33, 34^t, 35^f, 36^f
 - Operational lifetime, 19
 - Operators
 - coexistence between operators
 - in geographical area in band, 351
 - of TDD systems, 351
 - colocation of BS equipment between, 351
 - of mobile systems, 352
 - Orthogonal frequency-division multiplexing (OFDM), 39–40, 61, 103–104, 314–315, 349, 408
 - modulator output, 328
 - OFDM-based downlink and uplink, 175–181
 - OFDM-based physical layer, flexible, 360–361
 - OFDM-based transmission, 2
 - spectrum of OFDM signal, 367–368
 - symbols, 126, 283, 314–315, 318–319
 - Orthogonal sequences, 176
 - Orthogonality, 328
 - OSDDs. *See* OTA sensitivity direction declarations (OSDDs)
 - OTA. *See* Over-the-air (OTA)

OTA sensitivity direction declarations (OSDDs), 378–379

Out-of-band (OOB), 32

- domain, 367
- emission mask in, 368–370
- emissions, 366–367

Output power and dynamic range

- BS, 365
- device, 365–366

Output power level requirements, 361

- conducted, 365–366

Outside operating band (OOB blocking), 375

Over-the-air (OTA), 349, 378

- sensitivity, 378–379
- testing, 357–358

P

PA. *See* Power amplifier (PA)

Packet Data Convergence Protocol (PDCP), 81,

- 83–85, 273–276
- header, 82–83
- layer, 71
- protocol, 82–83, 254
- layers, 253–254
- retransmission functionality, 275

PAE. *See* Power-added efficiency (PAE)

Paging Channel (PCH), 87–88, 155

Paging Control Channel (PCCH), 87, 266

Paging message transmission, 101–102

Paired bands, 27–28

Pairwise coherence, 238

Paralleling technique, 397

Partial coherence, 238

Path-loss estimate (*PL* estimate), 304–307

Payload transmitted on PDCCH, 186

PBCH. *See* Physical Broadcast Channel (PBCH)

PBR. *See* Prioritized bit rate (PBR)

PCB. *See* Printed circuit board (PCB)

PCCH. *See* Paging Control Channel (PCCH)

PCell. *See* Primary cell (PCell)

PCF. *See* Policy Control Function (PCF)

PCH. *See* Paging Channel (PCH)

PCI. *See* Physical cell identity (PCI)

PDC. *See* Personal Digital Cellular (PDC)

PDCCH. *See* Physical Downlink Control Channel (PDCCH)

PDCP. *See* Packet Data Convergence Protocol (PDCP)

PDSCH. *See* Physical Downlink Shared Channel (PDSCH)

PDU. *See* Protocol Data Unit (PDU)

Peak data rate, 17

Peak spectral efficiency, 17

Per-CB CRC, 158

Per-CBG retransmission, 259–260, 260*f*

Per-slot scheduling, 91

Performance characteristics, 361

Periodic CSI-RS transmission, 139

Periodic reporting, 146–147

Periodic SRS, 151, 242

Personal Digital Cellular (PDC), 1–2

Phase Locked Loop (PLL), 392–393

Phase noise (PN), 391–395

- challenges with mm-wave signal generation, 393–395
- characteristics of free-running oscillators and PLLs, 392–393

Phase-tracking reference signals (PT-RS), 174,

- 183–184, 184*f*

pHEMT devices, 394–395

PHY. *See* Physical Layer (PHY)

Physical Broadcast Channel (PBCH), 70, 96,

- 313–315, 319–323
- information carried within, 322*t*
- PBCH/MIB, 324

Physical cell identity (PCI), 321

Physical channel, 96

Physical data shared channels. *See* Physical Downlink Shared Channel (PDSCH)

Physical Downlink Control Channel (PDCCH), 41,

- 66–67, 96, 185–189, 186*f*, 187*f*, 196*f*, 250, 297
- transmission, 248–249

Physical Downlink Shared Channel (PDSCH), 69,

- 96, 141
- downlink, 163
- PDSCH/PUSCH allocation, 183
- transmission, 248–249

Physical Layer (PHY), 82, 95–96, 155

Physical Random-Access Channel (PRACH), 96,

- 324–325

Physical resource blocks, 110–112, 111*f*, 168

Physical resource-block groups (PRGs), 166, 166*f*, 235

Physical Uplink Control Channel (PUCCH), 41,

- 67–68, 96, 146, 213, 214*f*
- format 0, 215–217, 216*f*
- format 1, 217–219, 218*f*
- format 2, 219–220, 220*f*
- format 3, 220–222, 221*f*
- format 4, 222, 222*f*
- groups, 116–117
- power control for, 308–309
- PUCCH-related information, 202
- reporting, 295
- resource
- indicator, 262

- and parameters for transmission, 223
 - sets, 223, 224*f*
 - structure, 214–215
 - Physical Uplink Shared Channel (PUSCH), 96, 146
 - reporting, 295
 - transmission, 120, 303, 306–307
 - power-control for, 304
 - uplink, 163
 - control signaling on, 223–225
 - Physical-layer control
 - channels, 68
 - signaling
 - downlink, 185–212
 - uplink, 212–225
 - Physical-layer hybrid-ARQ functionality, 155–156, 160–162
 - bit interleaver, 162*f*
 - circular buffer for incremental redundancy, 161*f*
 - Picocell, 364
 - PL* estimate. *See* Path-loss estimate (*PL* estimate)
 - Planar devices, 394–395
 - Platooning, 54
 - PLL. *See* Phase Locked Loop (PLL)
 - PMI. *See* Precoder matrix indicator (PMI)
 - PN. *See* Phase noise (PN)
 - Point A (reference point), 110–111
 - Polar code, 188
 - Policy Control Function (PCF), 75
 - Power
 - availability, 294–295
 - back-off, 368
 - consumption, 300
 - headroom reports, 294–296, 296*f*
 - ramping, 333
 - Power amplifier (PA), 368, 395–397
 - efficiency in relation to unwanted emission, 395–398
 - output power vs. frequency, 396*f*
 - saturated power-added efficiency vs. frequency, 398*f*
 - Power control, 295–296, 303
 - power-control commands, 303, 306
 - power-control-related information, 205
 - for PUCCH, 308–309
 - for PUSCH transmissions, 304
 - Power-added efficiency (PAE), 398
 - Power-spectral density (PSD), 408
 - PRACH. *See* Physical Random-Access Channel (PRACH)
 - Preamble, 328
 - power control, 333
 - sequence, 328
 - structure, 328
 - generation of NR random-access preamble, 329*f*
 - Preamble format, 330
 - for long preambles, 330*r*
 - for short preambles, 331*t*
 - Preamble transmission, 325–333
 - basic preamble structure, 328
 - beam establishment during initial access, 332–333
 - characteristics, 326–327
 - guard-time needs for, 326*f*
 - long vs. short preambles, 328–332
 - preamble power control and power ramping, 333
 - RACH resources, 327
 - Precoder codebook, 233
 - Precoder matrix, 41, 231
 - Precoder matrix indicator (PMI), 145, 233
 - Precoder-based uplink transmissions, 181
 - Precoding information, 167
 - Preemption, 67
 - indication, 205
 - indicator, 283
 - PRGs. *See* Physical resource-block groups (PRGs)
 - Primary cell (PCell), 116
 - Primary second cell (PSCell), 116–117, 213
 - Primary Synchronization Sequence. *See* Primary Synchronization Signal (PSS)
 - Primary Synchronization Signal (PSS), 70, 313–316, 319–323, 320*f*
 - PSS/SSS, 313–314
 - sequences, 320
 - of SS block, 319
 - Prime-length ZC sequences, 328
 - Printed circuit board (PCB), 402
 - Prioritized bit rate (PBR), 290
 - Protocol Data Unit (PDU), 82
 - sessions, 79, 79*f*
 - PSCell. *See* Primary second cell (PSCell)
 - PSD. *See* Power-spectral density (PSD)
 - Pseudo-random sequence, 176–179, 193
 - PSS. *See* Primary Synchronization Signal (PSS)
 - PT-RS. *See* Phase-tracking reference signals (PT-RS)
 - PUCCH. *See* Physical Uplink Control Channel (PUCCH)
 - PUSCH. *See* Physical Uplink Shared Channel (PUSCH)
- Q**
- QCL, 147–148, 249
 - QFI. *See* Quality-of-service flow identifier (QFI)
 - QPSK, 365, 374

Quality-of-service (QoS), 79
 flows, 79, 79f
 handling, 79

Quality-of-service flow identifier (QFI), 79, 83

Quasi-colocation, 130–131

Quasi-cyclic LDPC codes, 159

R

RA-RNTI, 199, 334

RACH. *See* Random-Access Channel (RACH)

Radiated base-station

 requirements in FR1, 378–379

 requirements in FR2, 379–380

Radiated device requirements in FR2, 377–378

Radiated interface boundary (RIB), 359

Radiated RF requirements for NR, 377–380

 BS, 357–359

 radiated base-station requirements

 in FR1, 378–379

 in FR2, 379–380

 radiated device requirements in FR2, 377–378

Radiated transmit power, 378

Radiated unwanted emissions requirements,
 378–380

Radio

 access, 39–41

 communication, 227–228

 distribution network, 358–359

 protocol architecture, 80

Radio Access Network (RAN), 23, 73, 76–78,
 77f, 335

Radio frequency (RF), 8, 23, 395–397. *See also*
 Reference signal(s)

 ADC and DAC considerations, 390–391

 bandwidth, 381–382

 channel bandwidth and spectrum utilization,
 353–356

 characteristics, 349

 conducted RF requirements for NR, 360–366
 band-specific device requirements through
 network signaling, 363–364

 BS classes, 364–365

 conducted output power level requirements,
 365–366

 conducted receiver characteristics, 362

 conducted transmitter characteristics, 361
 regional requirements, 362–363

 conducted sensitivity and dynamic range, 374
 conducted unwanted emissions requirements,
 367–374

 developments of RF requirements for NR,
 380–387

 MSR base station, 380–382

 multiband-capable base stations, 382–385

 operation in noncontiguous spectra, 386–387

 exposure above 6 GHz, 36–37

 filtering, 398–404

 filters, 409

 LO generation and phase noise aspects,
 391–395

 PA efficiency in relation to unwanted emission,
 395–398

 radiated RF requirements for NR, 377–380

 receiver noise figure, DR, and bandwidth

 dependencies

 carrier frequency and mm-wave technology
 aspects, 408–411

 compression point and gain, 407–408

 noise factor and noise floor, 406–407

 PSD and DR, 408

 receiver and noise figure model, 405

 receiver susceptibility to interfering signals,
 374–376

 requirements, 352–353

 in different FRs, 352–353

 spectrum flexibility implications, 349–352

 structure

 of BS, 357–360

 of BS RF requirements, 357–360

 conducted and radiated RF requirements for
 NR BS, 357–359

 of device, 356–357

 technologies at mm-wave frequencies, 389

 transmitted signal quality, 366–367

Radio Interface Specifications (RSPCs), 10

Radio Interface Technologies (RITs), 10

Radio Regulations, 9

Radio Resource Control (RRC), 97

 RRC RAN Notification Area Update, 101

 RRC-IDLE state, 97–98

 RRC-signaled pattern, 126

 RRC_ACTIVE state, 97–98

 RRC_CONNECTED state, 98–99

 RRC_INACTIVE state, 97–99

 signaling, 298

 state machine, 97–99, 98f

Radio resource management (RRM), 23, 77, 145

Radio-access technologies (RAT), 342, 380

Radio-interface architecture. *See also* New Radio
 (NR)

 control-plane protocols, 97–102

 overall system architecture, 73–78

 combinations of core networks and radio-
 access technologies, 76f

 5G core network, 74–76

 high-level core network architecture, 75f

 radio-access network, 76–78, 77f

- QoS handling, 79
- radio protocol architecture, 80
- user-plane protocols, 80–96, 82*f*
- Radio-Link Control (RLC), 66, 82, 85–86, 85*f*, 266–273, 268*f*. *See also* New Radio (NR)
 - acknowledged mode and RLC retransmissions, 269–273
 - generation of RLC PDUs from RLC SDUs, 270*f*
 - PDUs, 83
 - protocol, 83, 253–254
 - retransmissions, 269–273
 - sequence numbering and segmentation, 267–269
- Radio-link failure (RLF), 249–250
- RAN. *See* Radio Access Network (RAN)
- RAN Area Identifier (RAI), 100
- RAN Areas, 100–101, 100*f*
- RAN Notification Area, 101
- Random access, 313, 324–337
 - channel, 155–156
 - contention resolution, 335
 - and connection set up, 335–336
 - preamble, 70, 325
 - transmission, 325–333
 - procedure, 325
 - random-access-related MAC control elements, 89
 - response, 334–335
 - for SUL, 336–337
- Random-Access Channel (RACH), 88
 - configuration period, 327
 - occasions, 327
 - resources, 327, 327*f*, 330
 - slots, 327, 330
- Random-Access Response (RAR), 324–325, 334–335
- Range of angle of arrival (RoAoA), 378–379
- Rank indicator (RI), 145, 233
- RAR. *See* Random-Access Response (RAR)
- RAT. *See* Radio-access technologies (RAT)
- Rate matching, 188
 - and physical-layer hybrid-ARQ functionality, 160–162
- Re-farming, 31
- Receiver
 - characteristics, 362, 363*t*
 - intermodulation, 375
 - multiantenna processing, 243
 - noise figure, 405–411
 - and noise figure model, 405
 - simplified receiver model, 406*f*
 - zero-IF transceiver schematic, 406*f*
 - receiver-bandwidth adaptation, 62, 112–113, 280
 - receiver-side directivity, 227
 - susceptibility to interfering signals, 362, 374–376, 378, 380
 - BS and device requirements for receiver susceptibility, 376*f*
- Recovery-request transmission, 250
- Redundancy version (RV), 160
- Reference sensitivity, 374
 - and dynamic range, 378, 380
- Reference signal received power (RSRP), 145, 336
- Reference signal(s), 174–184, 217–219. *See also*
 - Radio frequency (RF)
 - demodulation
 - for DFT-precoded OFDM uplink, 181–183
 - for OFDM-based downlink and uplink, 175–181
 - occasions, 40
 - PT-RS, 183–184
 - structure, 47, 179–181
- Reflective mapping, 79
- Regional requirements, 362–363
- REGs. *See* Resource–element groups (REGs)
- Regulatory bodies and administrations, 8, 9*f*
- Relative power tolerance, 366
- Relay node, 49
- Relaying, 49, 49*f*
- Release-independent frequency-band principles, 351–352
- Reliability, 19
- Remaining minimum system information (RMSI), 324
- Remaining system information, 324
- “Repetition” flag, 247
- Report configurations, 142, 144–145, 233
- Requirements phase, 22
- Reserved resources, 61, 160, 171
- Resilience, 19
- Resource
 - allocation
 - type 0, 170
 - type 1, 170, 207
 - blocks, 91, 109
 - configuration, 146
 - element, 109
 - grids, 109–111, 111*f*
 - mapping, 167–171, 169*f*
- Resource–element groups (REGs), 188
 - bundle, 191
- Retransmission, 161, 259. *See also* Transmission
 - functionality, 253–254, 275
 - protocols
 - hybrid-ARQ with soft combining, 254–265
 - PDCP, 273–276
 - RLC protocol, 266–273, 268*f*

- RF. *See* Radio frequency (RF)
 - RI. *See* Rank indicator (RI)
 - RIB. *See* Radiated interface boundary (RIB)
 - RITs. *See* Radio Interface Technologies (RITs)
 - RLC. *See* Radio-Link Control (RLC)
 - RLF. *See* Radio-link failure (RLF)
 - RMSI. *See* Remaining minimum system information (RMSI)
 - RoAoA. *See* Range of angle of arrival (RoAoA)
 - Robust header compression (ROHC), 83, 273–275
 - ROHC. *See* Robust header compression (ROHC)
 - Root index of Zadoff–Chu sequence, 149
 - RRC. *See* Radio Resource Control (RRC)
 - RRM. *See* Radio resource management (RRM)
 - RSPCs. *See* Radio Interface Specifications (RSPCs)
 - RSRP. *See* Reference signal received power (RSRP)
 - Rural-eMBB, 21
 - RV. *See* Redundancy version (RV)
- S**
- Saturation velocity (V_{sat}), 409
 - SCells. *See* Secondary cells (SCells)
 - SCG. *See* Secondary Cell Group (SCG)
 - Scheduled carriers, 264
 - Scheduler, 91
 - Scheduling, 66–67, 91–93, 296–297
 - assignments, 116, 278
 - decisions, 41
 - discontinuous reception, 298–302
 - dynamic downlink, 277–283
 - and dynamic TDD, 296–297
 - dynamic uplink, 283–296
 - grants, 116, 285
 - request, 290–292, 293*f*
 - scheduling-related MAC control elements, 89
 - transmission without dynamic grant, 297–298, 299*f*
 - Scrambling, 162–163
 - SDAP. *See* Service Data Application Protocol (SDAP)
 - SDL bands. *See* Supplementary Downlink bands (SDL bands)
 - SDOs. *See* Standards Developing Organizations (SDOs)
 - SDPA. *See* Service Data Adaptation Protocol (SDPA)
 - SDU. *See* Service Data Unit (SDU)
 - Search spaces, 195–199, 198*f*
 - Second generation (2G)
 - of mobile communication, 1–2, 389
 - technologies, 1–2
 - Secondary Cell Group (SCG), 84
 - Secondary cells (SCells), 116
 - Secondary node, 340
 - Secondary synchronization signal (SSS), 70, 313–316, 319–323
 - sequence, 321
 - of SS block, 319
 - Security and privacy, 19
 - Segmentation, 85–86, 85*f*, 267–269
 - Segmentation information (SI), 267
 - Segmentation offset (SO), 267
 - Self-contained slots, 67–68
 - Self-interference, 342–343
 - Self-scheduling, 116, 116*f*, 279, 280*f*
 - SEM. *See* Spectrum emissions mask (SEM)
 - Semipersistent
 - CSI-RS transmission, 139–140
 - reporting, 147
 - scheduling, 297
 - SRS, 151, 242
 - Semistatic codebook, 264
 - Semistatic scheduling, 277
 - Sensitivity and dynamic range requirements, 362
 - Sequence
 - index, 182–183
 - numbering, 267–269
 - Service Data Adaptation Protocol (SDPA), 82–83
 - Service Data Application Protocol (SDAP), 81
 - Service Data Unit (SDU), 82
 - Service-based architecture, 74
 - Session Management Function (SMF), 74–75
 - 700 MHz band, 31
 - SFI. *See* Slot-format indication/indicator (SFI)
 - SFN. *See* System frame number (SFN)
 - Shannon channel capacity, 305
 - Sharp filtering, 401
 - Shift coefficients, 160
 - Short preambles, 328–332, 331*t*
 - formats for long preambles, 330*t*
 - RACH time-domain occasions within RACH slot, 331*t*
 - Short PUCCH formats, 214
 - Short TTI (sTTI), 43, 54
 - Shorter SS-block periodicity, 316
 - SI. *See* Segmentation information (SI)
 - SI-RNTI. *See* System Information RNTI (SI-RNTI)
 - SIBs. *See* System Information Blocks (SIBs)
 - Sidelink
 - connectivity, 417
 - transmission, 57
 - Signal-to-noise-and-distortion ratio (SNDR), 390–391
 - SNDR-based Schreier FoM, 390–391

- Signaling
 - of frequency-domain resources, 206–209
 - to support beam-management procedures, 69
 - of time-domain resources, 209–211
 - of transport-block sizes, 211–212
- Signaling radio bearers (SRBs), 97
- Simplified receiver model, 405, 406*f*
- Simulation, 21
- Single radio-access technology, 414
- Single-antenna transmission, 130
- Single-panel CSI, 235–236, 235*f*
- Single-port CSI-RS, 139
- Single-TX operation, 342–344
- Single-user MIMO, 41
- SiP. *See* System-in-package (SiP)
- Sixteen-QAM signal $\Psi 16\Psi$, 374, 391, 392*f*
- Slot, 107
 - aggregation, 211
 - format, 124–128, 125*f*
- Slot-format indication/indicator (SFI), 124–128, 125*f*, 127*f*, 205
- Small cells, 48–52
 - on/off, 49–50
- SMF. *See* Session Management Function (SMF)
- SNDR. *See* Signal-to-noise-and-distortion ratio (SNDR)
- SO. *See* Segmentation offset (SO)
- SoC. *See* System-on-chip (SoC)
- Soft combining, 161, 254–265
 - hybrid-ARQ with
 - downlink hybrid-ARQ, 259–260
 - dynamic hybrid-ARQ acknowledgment
 - codebook, 265*f*
 - multiplexing of hybrid-ARQ
 - acknowledgments, 262–265
 - semistatic hybrid-ARQ acknowledgment
 - codebook, 263*f*
 - timing of uplink acknowledgments, 260–262, 261*f*
 - uplink hybrid-ARQ, 260
- Sounding reference signals (SRS), 92, 133, 147–153, 167, 174, 310. *See also* Channel-state-information reference signals (CSI-RS)
- comb-based frequency multiplexing, 149*f*
- control commands, 206
- mapping to physical antennas, 152–153
- multiport, 150–151, 150*f*
- resource set, 151
- sequences, 149–150
- time-domain structure, 151
- time/frequency structures, 148*f*
- Zadoff–Chu sequences, 149–150
- Sparse frequency raster, 70
- Sparse SS-block raster, 70
- Sparse synchronization raster, 316
- Spatial filtering, 143–144
- Spatial multiplexing, 103, 179–181, 227
- Spectrum, 415, 418–419
 - for 5G
 - frequency bands for NR, 32–36
 - global spectrum situation for 5G, 31–32
 - new IMT bands under study in ITU-R TG 5/1, 30*f*
 - RF exposure above 6 GHz, 36–37
 - spectrum defined for IMT systems by ITU-R, 28–31
 - spectrum for mobile systems, 27–32
 - allocations
 - aggregation, 352
 - diverse, 350
 - analyzers, 352
 - and bandwidth flexibility, 19
 - block definitions, 350
 - coexistence, 339–340
 - efficiency, 18
 - flexibility, 39, 43–46, 59, 121, 349, 354
 - CA, 44–45, 44*f*
 - implications, 349–352
 - LAA, 45–46, 46*f*
 - full duplex on link level vs. cell level, 419*f*
 - mask, 364
 - for mobile systems, 27–32
 - of OFDM signal, 367–368
 - regulation, 8
 - utilization, 353–356, 356*r*
- Spectrum emissions mask (SEM), 367
 - device, 370
- Spider web” diagrams, 16, 16*f*
- Split bearers, 84
- Spurious domain, 367
- Spurious emissions, 367, 373
- Spurious response frequencies, 375
- SRBs. *See* Signaling radio bearers (SRBs)
- SRI. *See* SRS resource indicator (SRI)
- SRS. *See* Sounding reference signals (SRS)
- SRS resource indicator (SRI), 167, 205, 239–242
- SS block. *See* Synchronization Signal block (SS block)
- SS-block periodicity, 316
- SSS. *See* Secondary synchronization signal (SSS)
- Stacking technique, 397
- Standards Developing Organizations (SDOs), 7
- Static frequency-domain sharing, 344–345
- Static split, 50–51
- sTTI. *See* Short TTI (sTTI)
- Subcarrier spacing, 107
- Subframe(s), 106–107, 107*f*

- Subframe(s) (*Continued*)
 - duration of 1 ms, 40
 - Submission template, 13
 - Suitable beam pair, 243–245
 - adjusted downlink, 245
 - in downlink direction, 244*f*
 - suitable downlink, 247–248
 - suitable transmitter/receiver, 243–244
 - SUL. *See* Supplementary uplink (SUL)
 - Supplementary Downlink bands (SDL bands), 27–28, 120, 351
 - Supplementary uplink (SUL), 71–72, 117–120, 118*f*, 119*f*, 351
 - bands, 27–28
 - control signaling, 120
 - random access for, 336–337
 - relation to carrier aggregation, 119–120
 - SUL/non-SUL indicator, 120
 - Synchronization raster, 115, 316
 - Synchronization Signal block (SS block), 70, 134, 146, 244–246, 248, 250, 313–315
 - burst set, 317–319, 317*f*
 - time-domain locations of SS block within, 318*f*
 - frequency-domain position, 315–316
 - numerologies and frequency ranges, 315*t*
 - periodicity, 316–317
 - time index, 322–323, 332
 - time–frequency structure of single SS block, 314*f*
 - Synchronous hybrid-ARQ protocol, 186
 - System frame number (SFN), 106–107
 - System Information Blocks (SIBs), 324
 - SIB1, 323–324
 - configuration, 323
 - numerology, 323
 - reception, 323
 - System Information RNTI (SI-RNTI), 324
 - System-in-package (SiP), 409
 - System-level simulations, 21
 - System-on-chip (SoC), 409
- T**
- TAB. *See* Transceiver array boundary (TAB)
 - TACS. *See* Total Access Communication System (TACS)
 - Tactile internet, 14–15
 - TAGs. *See* Timing advanced groups (TAGs)
 - TAI. *See* Tracking Area Identifier (TAI)
 - Target received power, 304
 - TC-RNTI, 334, 336
 - TCI. *See* Transmission Configuration Index (TCI)
 - TD-SCDMA, 2
 - tDAI. *See* Total DAI (tDAI)
 - TDD. *See* Time Division Duplex (TDD)
 - TDM. *See* Time-domain sharing (TDM)
 - Technical requirements, 13
 - Technical Specifications (TS), 25
 - Technical Specifications Groups (TSGs), 23
 - Technology, 419
 - “Technology-neutral” manner, 351–352
 - Test environments, 21
 - Testing and verification phase, 23
 - TF. *See* Transport Format (TF)
 - TG 5/1 task group, 30
 - Third generation (3G), 1–2
 - mobile communication, 389
 - Third generation of mobile communication, 1–2
 - Third-Generation Partnership Project (3GPP), 2–3, 7, 359, 377, 380–381, 414
 - organization, 24*f*
 - process, 22–25
 - radio-access technologies, 380
 - specifications, 382, 389
 - of 5G, 25–26
 - standardization, 22–26
 - phases and iterative process, 22*f*
 - timeline, 58*f*
 - Third-order intercept point (IP3), 407
 - 32-port CSI-RS, 137, 139*f*
 - 3D gaming, 14–15
 - Time domain, 166, 171–172, 225
 - allocation, 209, 210*f*
 - for DM-RS, 176
 - bitmap, 172
 - property of CSI-RS configurations, 139–140
 - resource
 - allocation, 204
 - signaling, 209–211
 - structure, 106–108
 - of SRS, 151
 - windowing, 367–368
 - Time index, 319
 - Time multiplexed reference signals, 181–182
 - Time Division Duplex (TDD), 1–2, 27–28, 39, 64, 121–123
 - carrier, 344
 - coexistence between operators of TDD systems, 351
 - operation, 365
 - scheme, 418
 - TDD-capable device, 45
 - Time-domain sharing (TDM), 135
 - Time–frequency
 - resource, 168, 189
 - time/frequency-domain CDM, 137
 - time–frequency-code resources, 223

- Timing advanced groups (TAGs), 312
 - Timing-advance, 310–311, 311*f*
 - MAC control elements, 89
 - TM. *See* Transparent mode (TM)
 - Total Access Communication System (TACS), 1
 - Total DAI (tDAI), 264–265
 - Total radiated power (TRP), 377
 - Tracking Area Identifier (TAI), 100
 - Tracking Areas, 100–101, 100*f*
 - Tracking device, 100–101
 - Tracking reference signal (TRS), 142–143, 143*f*, 174
 - Traffic
 - channel, 86–87
 - situation, 51
 - Transceiver array boundary (TAB), 358–359
 - Transceiver unit array, 358–359
 - Transmission, 259
 - bandwidth configuration, 354
 - to device A and B, 283
 - without dynamic grant, 297–298, 299*f*
 - parameters, 298
 - rank, 41
 - scheme, 61–64, 103–106
 - structure
 - antenna ports, 128–130, 129*t*
 - BWPs, 112–114, 113*f*
 - carrier aggregation, 115–117
 - duplex schemes, 121–128
 - frequency-domain location of NR carriers, 114–115
 - frequency-domain structure, 109–112
 - quasi-colocation, 130–131
 - subcarrier spacings supported by NR, 105*t*
 - SUL, 117–120, 118*f*, 119*f*
 - symbol alignment, 106*f*
 - time-domain structure, 106–108
 - transmission scheme, 103–106
 - timing of NR uplink transmissions, 326
 - Transmission Configuration Index (TCI), 165, 193–194, 248–249
 - Transmission configuration indication.
 - See* Transmission Configuration Index (TCI)
 - Transmission Reception Point (TRP), 18
 - Transmission Time Interval (TTI), 87, 155
 - Transmit multiple multipoint SRS, 239–240
 - Transmit-timing advance, 310
 - Transmitted signal quality, 366–367, 378–379
 - BS time alignment, 367
 - device in-band emissions, 366
 - EVM and frequency error, 366
 - requirements, 361
 - Transmitter
 - characteristics, 361, 362*t*
 - intermodulation, 373–374
 - requirements, 361
 - Transparent mode (TM), 85, 266
 - Transport block(s), 87, 157
 - sizes signaling, 211–212, 212*f*
 - transport-block-related information, 201–202, 204
 - Transport channels, 86–91
 - processing, 156*f*
 - channel coding, 157–160
 - downlink reserved resources, 171–173
 - layer mapping, 163
 - modulation, 163
 - multiantenna precoding, 164–167
 - rate matching and physical-layer hybrid-ARQ functionality, 160–162
 - reference signals, 174–184
 - resource mapping, 167–171
 - scrambling, 162–163
 - uplink DFT precoding, 164
 - transmission, 167–168
 - types, 87–88
 - Transport Format (TF), 87, 304
 - Transport-format selection, 87
 - TRP. *See* Total radiated power (TRP)Transmission Reception Point (TRP)
 - TRS. *See* Tracking reference signal (TRS)
 - TS. *See* Technical Specifications (TS)
 - TSG RAN, 23
 - TSGs. *See* Technical Specifications Groups (TSGs)
 - TTI. *See* Transmission Time Interval (TTI)
 - 26 GHz band, 32
 - Two-dimensional beamforming, 46
 - Two-port CSI-RS, 136, 136*f*
 - Type 0, bitmap-based allocation scheme, 206–207
 - Type 1 power headroom reporting, 295
 - Type 2 power headroom reporting, 295
 - Type 3 power headroom reporting, 295
 - Type I CSI, 234–236
 - multipanel CSI, 234, 236
 - single-panel CSI, 234–236
 - Type II CSI, 236–237
- ## U
- UCI. *See* Uplink control information (UCI)
 - UDM. *See* Unified Data Management (UDM)
 - UE. *See* User Equipment (UE)
 - UE power class, 365
 - UE Registration Area, 101
 - UL-SCH. *See* Uplink Shared Channel (UL-SCH)
 - UL/SUL indicator, 204

- Ultra-Low-Latency and Reliable communication (URLLC), 4, 11–12, 14–15, 53, 416
 - Ultralean design, 59–60
 - Unacknowledged mode (UM), 85, 266–267
 - Unified Data Management (UDM), 75
 - Unlicensed spectra, operation in, 415–416
 - Unpaired bands, 27–28
 - Unwanted emissions
 - limits, 362
 - requirements, 361, 367–374
 - UPF. *See* User Plane Function (UPF)
 - Uplink, 155–156, 212–225, 418. *See also*
 - Downlink
 - acknowledgment timing, 260–262, 261f
 - beam adjustment, 247–248
 - codebook, 239, 239f
 - constraints, 344
 - control signaling on PUSCH, 223–225
 - DFT precoding, 164
 - hybrid-ARQ, 260
 - message, 335
 - orthogonality, 310
 - $\pi/2$ -BPSK, 163
 - precoding, 167, 182f
 - priority handling, 288–290
 - PUCCH
 - format 0, 215–217
 - format 1, 217–219
 - format 2, 219–220
 - format 3, 220–222
 - format 4, 222
 - structure, 214–215
 - reference
 - and parameters for PUCCH transmission, 223
 - signals, 182–183, 183f
 - scheduler, 91, 283
 - scheduling, 91
 - assignments, 308–309
 - grants, 202–205
 - sounding signals, 127
 - spatial multiplexing, 47
 - symbols, 126
 - timing control, 310–312
 - uplink-only coexistence, 346
 - uplink-path-loss estimate, 306
 - uplink–downlink allocation, 39, 65
 - Uplink channel sounding, 147–153. *See also*
 - Downlink channel sounding
 - mapping to physical antennas, 152–153
 - multiport SRS, 150–151, 150f
 - SRS resource set, 151
 - SRS sequences and Zadoff–Chu sequences, 149–150
 - time-domain structure of SRS, 151
 - Uplink control information (UCI), 67–68, 96
 - Uplink power control, 303–310. *See also* Beam-based power control
 - baseline power control, 304–306
 - beam-based power control, 306–308
 - in case of multiple uplink carriers, 309–310
 - commands, 206
 - for PUCCH, 308–309
 - Uplink Shared Channel (UL-SCH), 88, 155
 - Urban Macro-mMTC, 21
 - Urban Macro-URLLC, 21
 - URLLC. *See* Ultra-Low-Latency and Reliable communication (URLLC)
 - Usage scenarios, 11–12, 29
 - for IMT-2020, 14–16
 - User Equipment (UE), 74–75, 357
 - User experienced data rate, 18
 - User Plane Function (UPF), 74
 - User-plane protocols, 80–96, 82f. *See also*
 - Control-plane protocols
 - MAC, 86–95
 - PDCP, 83–85
 - physical layer, 95–96
 - RLC, 85–86, 85f
 - SDAP, 83
 - Uu interface, 77
- ## V
- Van diagram, 10, 11f
 - Vehicle-to-everything communication (V2X communication), 43, 54–55, 55f
 - Vehicle-to-vehicle communication (V2V communication), 14–15, 43, 54–55, 55f
 - Virtual resource blocks, 111–112, 168, 207
 - “Vision” recommendation, 11–12
 - Voltage-Controlled Oscillator (VCO), 392
- ## W
- WARC. *See* World Administrative Radio Conference (WARC)
 - Wi-Fi, 45–46, 415
 - Wideband CDMA (WCDMA), 3
 - Wideband reference signals, 193
 - Wireless
 - communication systems, 97–98
 - technology for backhaul, 413
 - wireless-backhaul solutions, 413
 - WLAN interworking, 51–52
 - Working Party 5D (WP5D), 9–10

World Administrative Radio Conference (WARC),
28–29
WARC-92, 28
World Radio-communication Conference (WRC),
9, 28–29
WRC-15, 12–13, 29
WRC-19, 12
WP5D. *See* Working Party 5D (WP5D)
WRC. *See* World Radio-communication
Conference (WRC)

X

Xn interface, 77

Z

Zadoff–Chu sequences (ZC sequences), 149–150,
182–183, 328
Zero-correlation zone parameter, 328
Zero-power CSI-RS (ZP-CSI-RS), 141–142