

Index

- 1xEV-DO, 4
- 1xEV-DV, 4
- 1G. *See* First generation
- 3GPP, 16, 108
- 4G. *See* Fourth generation
- 5G Forum, 14
- 5G Promotion group, 14
- 5G Radio access network, 39
- 5G System concept, 32
- 5G-PPP, 12

- Access reservation, 196, 198
- Access stratum, 65
- ADC. *See* Analog-to-digital converter
- Admission control, 324
- Advanced receivers, 179
- Almost blank subframes, 312
- ALOHA, 85, 199
 - frameless, 199
- Analog-to-digital converter, 141, 143, 144, 154
- Angle of arrival, 383
- Angle of departure, 383
- Angular resolution, 360
- Antenna aperture, 143
- Antenna beams, 41
- Anti-tromboning, 45
- API. *See* Application programming interface
- Application programming interface, 52, 69
- Architecture
 - functional, 53, 67
 - logical, 53, 55, 56, 58, 67
 - physical, 54, 67, 71
- ARIB 2020, 14
- Asynchronous communications, 183
- Asynchronous transmission, 169, 173
- Augmented reality, 29
- Autonomous driving, 78
- Autonomous vehicle, 23
- Availability, 30, 82, 99, 108
 - estimation and indication, 99
 - indication, 98, 99
- Backhaul, 42, 62, 71, 145, 146, 148, 251, 252, 260, 277, 288, 312, 324, 328, 397
 - coordinated direct and relay, 285
 - nomadic nodes, 281
 - self-backhauling, 145, 146, 147, 191, 279
- Backup connection, 148
- Bandwidth requirement, 343
- Battery life, 31, 81, 191
- Beam finding, 150
 - feedback-based, 150
 - random excitation, 152
- Beam scanning, 150, 151, 152
 - linear beam scan, 150
 - tree scan, 151
- Beamforming, 41, 137, 139, 140, 143, 149, 150, 153, 184, 187, 192, 208, 230, 233
 - analog, 143, 144, 149, 150, 153, 234
 - coordinated, 249
 - digital, 143, 144, 150, 153, 233
 - feedback, 150, 151, 152
 - hybrid, 143, 144, 150, 153, 234, 235, 239
 - weight, 143, 144, 150, 152
- Berg recursive model, 366, 367
- Broadcast channel, 165, 167
- Broadcast-to-broadcast, 193

- Calibration, 387
 - link-level, 388
 - system-level, 391
- Capacity regions, 165, 179
- Capture effect, 199
- Carrier aggregation, 5, 337
- Carrier sense multiple access, 193
- CDMA. *See* Code division multiple access
- CDMA 2000, 4
- CDMAOne, 3
- Centimeter wave, 35, 138, 145, 186, 340
- Centralized RAN. *See* Cloud radio access network
- Channel code, 183, 293
- Channel measurements, 372, 374
- Channel models, 241, 357, 379, 383
 - hybrid, 358
 - map-based, 363

- Channel models (cont.)
 path loss, 363, 371
 ray-tracing, 139, 363, 365, 383, 396
 requirements, 357, 359
 spatial consistency, 357
 stochastic, 357, 362, 371, 377
- Channel prediction, 252
- Cloud radio access network, 59, 308
- Clustering, 253, 310
 density-base spatial, 230
 dynamic, 268
- cmW. *See* Centimeter wave
- Code division multiple access, 4, 160, 164, 166, 183
 direct sequence, 164
 frequency hop, 164
- Coded random access, 85, 199, 221
- Collision, 196, 200
- Common phase error, 187
- Common system access, 43
- CoMP. *See* Coordinated multi-point
- Compressed sensing, 91, 152, 195
- Configuration
 flow based, 52
- Connected car, 78
- Connection density, 11, 30
- Consistency interval, 359, 360
- Contention-based transmission, 90, 182
- Context information, 303, 321
 applications, 304
- Control information, 83
- Control plane, 51
 diversity, 66
 function, 65
 processing, 61
 switching, 67
- Control/user plane decoupling, 44, 309, 326
- Coordinated multi-point, 5, 249
 opportunistic, 260
 small cells, 260
- Coordinated beamforming, 249
- Coordinated scheduler, 249
- Cost, 30
- Cover shift, 254
- Coverage, 137, 144–147, 150–151
- CSI-based precoding, 235
- CSMA. *See* Carrier sense multiple access
- Cyber-physical systems, 7, 79
- D2D. *See* Device-to-device communication
- Decentralized coordinated transceiver, 226
- Degree of freedom, 84
- Density-based spatial clustering of applications with noise, 230
- Deployment, 67, 144, 145, 147, 152, 304
 heterogeneous, 147
 overlay network, 147
 small cell, 137, 147, 152, 186
- Device-to-device communication, 42, 99, 107, 282, 315, 318, 348, 361, 396
- ad-hoc, 101
- cluster head, 124
- discovery, 108, 111, 112, 120, 121, 122, 127
- licensed spectrum, 129
- long term evolution, 110
- mode selection, 112, 114, 117, 118, 124, 125, 128, 129
- multi-cell, 116, 117
- multi-hop, 107, 108, 120, 122, 123
- multi-operator, 70, 113, 127, 128, 133
- network-assisted, 101
- offloading, 45
- overlay, 70, 128
- radio resource management, 107, 113, 114, 115, 120, 124
- relaying, 108, 121, 122
- resource pool, 110, 111
- spectrum allocation, 131
- synchronization, 109
- synchronization signal, 110
- synchronization source, 110
- TDD, 116
- ultra-dense network, 118
- underlay, 70, 128
- unlicensed spectrum, 129
- Discontinuous reception, 89
- Discrete fourier transform spread OFDM, 153
- Distributed cooperative transmission, 260
- Distributed network management, 107
- Diversity, 96, 148, 149, 296
 frequency, 47
 cooperative, 278
 multi-user, 100, 166
 polarization, 149, 192
 spatial, 178
 transmit, 390
- DRX. *See* Discontinuous reception
- Dual connectivity, 60, 147
- Dynamic activation, 323
- Dynamic frequency selection, 348
- Dynamic point selection, 249
- Dynamic radio access network, 33, 39
- Dynamic range, 144, 154
- Economy sector, 8, 23
 agriculture, 8
 automobile, 8
 construction, 8
 energy, 8
 finance, 8
 health, 8
 manufacturing, 8
 media, 8

- public safety, 9
- retail and consumer, 9
- transport, 9
- EDGE, 4
- EGPRS, 4
- Eigenmode, 235
- Electromagnetic field, 138
- Energy efficiency, 11, 31
- Energy performance, 45
- Energy savings
 - moving networks, 327
 - network, 323
- Engineering value of spectrum, 350, 352
- EXIT-charts, 293
- Extreme coverage, 34
- Extreme mobile broadband, 6, 32
 - spectrum needs, 47
- Factory automation, 79
- FBMC. *See* Filter bank multi-carrier
- FDD. *See* Frequency division duplexing
- FDMA. *See* Frequency division multiple access
- Figure-of-merit
 - analog-to-digital converter, 141
 - voltage controlled oscillator, 140, 141
- Filter bank multi-carrier, 169, 394
- Filter tails, 174
- First generation, 3
- Flexible duplex, 152
- Flexible network configuration and control, 69
- Flexible numerology, 153
- Flow
 - forward-backward, 61
 - straight, 61
- Fourth generation, 4
- Four-way relaying, 284, 287
- Frequency band, 337
- Frequency division duplexing, 109, 184
- Frequency division multiple access, 153, 160, 166
 - systems, 160
- Frequency selective scheduling, 179
- Fronthaul, 251
- Fuzzy logic, 322
- Fuzzy Q-Learning, 322
- Game theory, 310
- Generic 5G communication service, 32
- Geolocation database, 348
- GPRS, 3
- Grant-free access, 178
- Grating lobe, 151
- Handover
 - context awareness, 322
 - D2D, 319
 - interruption time, 316
 - network controlled, 316
 - UE assisted and network controlled, 316
 - UE controlled, 315
- HARQ, 190
- Heterogeneous networks, 306, 323, 324, 326
- High speed downlink packet access, 4, 308
- High speed packet access, 4
- High speed uplink packet access, 4, 308
- Horizontal spectrum manager, 349
- HSDPA. *See* High speed downlink packet access
- HSPA. *See* High speed packet access
- HSUPA. *See* High speed uplink packet access
- Hysteresis, 149
- IDMA. *See* Interleave division multiple access
- IEEE
 - 802.11ad, 16
 - 802.11ah, 16
 - 802.11ax, 16
 - 802.11ay, 16
 - 802.11p, 16
 - 802.15.4, 16
- IMT-Advanced, 10
- Industrial automation, 79
- Industrial internet consortium, 15
- Industrial manufacturing, 25
- Industrial revolution, 2
- Industrie 4.0, 15
- Information and communications technology, 1
- Information technology, 1, 2
- Inter-cell interference coordination, 73
- Interference alignment, 250, 265
- Interference cancellation, 292, 314
 - hard, 314
 - soft, 314
- Interference floor shaping, 256
- Interference management, 113, 306
- Interference mitigation framework, 257
- Interference rejection combining, 248, 308, 312
- Interleave division multiple access, 178, 183, 277, 292
 - layering, 292
- Internet of things, 1, 7, 11
- Interoperability, 55, 57
- Intra-cell interference, 221
- IoT. *See* Internet of things
- IRC. *See* Interference rejection combining
- Irregular repetition codes, 294
- Iterative receivers, 184
- ITU-R, 15
- Joint transmission, 249
- K-means algorithm, 231
- LAA. *See* Licensed assisted access
- Large scale parameters, 383, 384, 386
- Large system analysis, 226

- Latency, 11, 30, 190
 Lean system control plane, 33, 43
 Licensed assisted access, 337, 347
 Licensed shared access, 339
 Line-of-sight, 317
 Link performance, 154
 Local break out, 69
 Localized contents and traffic flows, 33, 45
 Logical channel, 65
 Long term evolution, 5, 56, 63, 65, 67
 unlicensed, 347
 LSA. *See* Licensed shared access
 LTE. *See* Long term evolution
- MAC, 160
 ad-hoc, 192
 centralization, 59
 coded slotted aloha, 193
 efficiency, 201
 layer, 62, 65, 138, 145, 146, 147
 Machine to machine, 7
 Machine-type communication, 32, 36, 77, 178, 184,
 194, 282
 access types, 37
 massive MTC, 33, 36, 78, 194
 mission-critical, 80
 spectrum needs, 47
 ultra-reliable MTC, 32, 38, 81
 ultra-reliable spectrum needs, 47
 Massive access problem, 195
 Massive MIMO, 56, 62, 189, 395
 Maximum ratio combining, 312
 MCS. *See* Modulation and coding scheme
 Medium access control. *See* MAC
 METIS, 12, 88, 137, 357, 358, 371, 372, 381
 Millimeter wave, 35, 137, 138, 139, 140, 141, 142,
 143, 144, 145, 146, 147, 148, 150, 152, 153,
 154, 186, 282, 315, 317
 mmW. *See* Millimeter wave
 MIMO. *See* Multiple input multiple output
 Mobile broadband, 184
 Mobility management, 149
 3G, 316
 4G, 316
 Modulation and coding scheme, 218, 293
 Moving networks, 41, 303, 307
 antennas, 305
 mobility, 315
 MTC. *See* Machine-type communication
 Multi radio access technology, 56, 62, 66
 Multi-carrier
 harmonized OFDM, 186
 OFDM frequency numerology, 187
 OFDM time numerology, 186
 Multi-flow wireless backhauling, 284
 Multiple access, 178
 Multiple input multiple output, 175, 208
 Multi-user detection, 199
 compressed sensing, 200
 Multi-user MIMO, 215
 Mutual renting, 130
- NAIC. *See* Network-assisted interference cancelation
 Nash equilibrium, 130
 NA-TDMA, 3
 National security and public safety, 35
 Network assistance, 271
 Network coding, 277, 291
 wireless network coding, 279
 Network densification, 303, 305, 306, 315
 Network element, 50, 53, 55, 74
 Network enhanced interference cancellation and
 suppression, 314
 Network function, 51, 53, 55, 57, 58, 59, 60,
 62, 69, 70
 configuration flow based, 52
 pool, 68
 split, 59
 Network function virtualization, 2, 9, 17, 50, 146
 infrastructure, 51
 Network nodes, activation and deactivation of, 42
 Network slice, 69
 Network-assisted interference cancelation,
 248, 271
 Nodes, activation and deactivation of, 42
 NOMA. *See* Non-orthogonal multiple access
 Nomadic nodes, 41, 305, 327, 329
 Non-cooperative game, 130
 Non-orthogonal multiple access, 85, 178, 280, 292
- OFDM. *See* Orthogonal frequency division
 multiplexing
 OFDMA. *See* Orthogonal frequency division multi-
 ple access
 Open loop transmission, 179
 OpenFlow, 52
 Optimization, 211
 Orchestrator, 69
 Orthogonal frequency division multiple access, 160,
 163, 167
 systems, 162
 Orthogonal frequency division multiplexing, 153,
 154, 155, 162, 217
 Overloaded system, 181
 Overloading, 178
- Packet data convergence protocol, 60, 65
 Parallel interference cancellation, 314
 Path loss, 383, 384, 386
 Peak to average power ratio, 153, 154
 Performance indicators, 381
 application data rate, 382
 bit error rate, 382
 cell throughput, 382

- cost, 383
- data link layer delay, 383
- end-to-end delay, 383
- frame error rate, 383
- network energy performance, 383
- spectral efficiency, 382, 391, 392
- traffic volume, 382
- user throughput, 381
- Personal digital cellular, 3
- Phantom cell, 147, 323, 326
- Phantom codewords, 198
- Phase noise, 140, 141, 153, 187
- Physical layer, 51, 61, 64, 138, 145, 146, 152, 155
- Physical nodes, 54, 55
- Pilot contamination, 220
- Pilot design, 217
- Pilot power control, 221
- Pilot reuse, 218
- Power amplifier, 139, 154
- Power capability, 139, 154
- Power consumption, 140, 141, 142, 144, 150
- Power control, 114
- Power saving mode, 90
- Precoding, 208, 233
 - CSI-based, 235
- Predictor antenna, 313
- Propagation, 137, 139, 145, 149, 153, 357, 379
 - atmospheric loss, 139
 - body loss, 139
 - diffraction, 139, 147, 363, 365, 367
 - environment, 359, 363, 364
 - foliage loss, 139
 - free space, 139
 - Madrid model, 88
 - outdoor to indoor, 139, 145, 147
 - rain attenuation, 139
 - reflection, 363, 365, 367
 - scatterers, 361, 365, 367
 - scattering, 139, 152, 363, 364, 365, 367, 371
- Protocol
 - contention-based, 160
 - contention-free, 160
 - layers, 61
 - stack, 61, 64, 68
- Proximity, 108, 109, 120, 125
- Public safety, 107, 108, 109, 121
- PUSCH, 108, 110

- QuaDRiGa, 242
- Quality of service, 82, 219

- Radio access network technology, 62
- Radio edge, servers and contents close to, 46
- Radio fingerprints, 318
- Radio frequency
 - hardware complexity, 233
 - imperfections, 175
- Radio link control, 65
- Radio network controller, 308
- Radio resource control, 60, 65, 66
- Radio resource management
 - 4G, 308
 - centralized, 308, 310, 326
 - context awareness, 310
 - decentralized, 308, 310
 - moving networks, 311, 312
 - over-the-air signaling, 309
 - signaling, 309, 310
- Random access, 85, 197, 324
 - direct, 197, 199
 - channel, 195
- Random matrix theory, 211
- Rate adaptation, 293
- Regularized zero forcing, 232
- Relay, 277
 - buffer-aided, 277, 280, 295
 - coordinated direct and relay transmission, 285
 - decode-and-forward, 285
 - full-duplex, 277, 280
 - half-duplex, 277, 311
 - in-band, 277, 278
 - max-max selection, 297
 - moving nodes, 41, 305, 330
 - multi-flow relaying, 280
 - non-orthogonal multiple access, 277
 - out-of-band, 278
 - space full-duplex, 296
 - two-way relaying, 279, 284, 290
- Reliability, 11, 30
 - definition, 82
 - gain, 112
 - impairment, 82
- Reliable service composition, 82, 96
- Remote control, 29
- Repeat accumulate, irregular, 294
- RRM. *See* Radio resource management

- SC-FDMA. *See* Single carrier frequency division multiple access
- SCMA. *See* Sparse code multiple access
- SDN. *See* Software defined networking
- Scheduling, 257
- Second generation, 3
- Security, 11, 30
- Self-organizing networks, 149, 321
- Service flow management, 69
- Service profile, 72
- Service-specific signaling, 44
- Serving base station, 148
 - assistant, 148
 - principal, 148
- Shadowing, 360, 363, 364, 370, 374, 375, 383
- SIC. *See* Successive interference cancellation

- Sidelink communication, 109
 Signal to interference plus noise ratio, 218
 Signal to noise ratio, 144, 150, 151, 152
 Signaling overhead, 195, 196
 Simulation, 381, 393
 guidelines, 381
 Single carrier frequency division multiple access, 109
 Single-carrier, 153, 154, 155
 Sleep mode, 326
 Small cell, 184, 186, 188, 258, 281, 284, 337
 discovery, 318
 Small-scale parameters, 383
 Smart city, 27
 Smart electricity meter, 79
 Smart grid, 28, 79
 Software defined networking, 2, 9, 50, 146
 controller, 69
 SON. *See* Self-organizing networks
 Sparse code multiple access, 91, 178, 181
 Spatial degrees of freedom, 208
 Spectrum, 357, 359
 Spectrum access option, 339
 common use, 339
 exclusive use, 339
 horizontal sharing, 339
 vertical sharing, 339
 Spectrum allocation, 129
 Spectrum authorization
 general, 345
 individual, 345
 Spectrum needs
 for mMTC, 47
 for uMTC, 47
 for xMBB, 47
 Spectrum overloading, 292
 Spectrum pooling, 130
 Spectrum toolbox, 33, 47, 346
 Spherical waves, 358, 359, 360, 377
 Spreading, 183
 Stieltjes transform, 226
 Successive interference cancellation, 85, 314
 Superposition, 182, 292
 Superposition coding, 179
 Synchronization, 251, 292
- TDD. *See* Time division duplexing
 TDMA. *See* Time division multiple access
 Teleprotection, 28
 Temporary network nodes, 41
 Terminal-specific serving cluster, 148
- Third generation, 4
 Time division duplex, 109, 184, 188
 dynamic TDD, 263, 308, 352
 flexible TDD, 308–309
 frame structure, 188
 Time division multiple access, 153, 160, 166
 systems, 161
 Tracking area update, 90
 Traffic
 mobile, 9
 offloading, 107
 Transmission time interval, 185
 Transport channels, 64, 65
- UFMC. *See* Universal filtered multi-carrier
 UF-OFDM. *See* Universal filtered OFDM
 Ultra dense networks, 40, 259, 260, 277, 350
 UMTS, 4
 Universal filtered multi-carrier, 394
 Universal filtered OFDM, 169, 175
 Uplink-downlink duality, 226
 User plane, 51
 aggregation, 67
 processing, 61
 switching, 67
- V2V. *See* Vehicle-to-vehicle communication
 Vehicle-to-anything communication, 38, 100, 397
 Vehicle-to-vehicle communication, 82, 112, 127, 129, 192
 Vehicular penetration loss, 305, 319
 Vehicular user, 319
 Virtual reality, 29
 Virtualized network function, 50, 51
 VNF. *See* Virtualized network function
- Wake-up signal, 326
 Waveforms, 159, 169
 Wi-Fi
 aware, 109
 direct, 109
 sharing mode, 347
 WiMAX, 5
 WLAN, 16
 Wireless personal area network, 16
 Wireless-emulated wired, 284, 288
- X2, 308
- Zadoff-Chu sequence, 196
 Zigbee, 16