Index

Page numbers in *italic* refer to figures. Page numbers in **bold** refer to tables.

acceleration sensors (accelerometers) 78, 78-80 comparison of open- and closed-loop systems 102 - 103computation of force and deflection 104 minimum deflection 79 responsivity 78 sensitivity 68-70 system design and scale estimate 107 thermal noise limit 80 vibration accelerometer 86-87, 87 ACID transactions 332 acoustic signal propagation 52-56, 55 acoustic properties of concert halls 54, 54 effects of relative humidity 53 wind and motion 53-54, 54 propagation velocity 53 speed of sound in various media 53 active pixel sensor (APS) devices 92, 93 active RFID tags 7 actuators for microsensor systems 103, 103-104 computation of force and deflection for accelerometer systems 104 ad hoc on-demand distance vector (AODV) routing 237 - 239ad hominem attacks 354 adaptive antennas 214 space division multiple access (SDMA) 214 adaptive cooperative networks 248-249 single winner election algorithm 248-249 adaptive data collection 349-350 variable sampling density 350, 350-351, 364 adaptive fidelity 322, 343 increasing lifetime 322-323 adaptive resource deployment 378-383 communicate or carry? 382, 382-383, 383, 393 dungeons and dragons 380-381, 381 obstructions 380, 380, 381, 393, 393 temperature calibration 383-384 triggering vs. searching 379, 379 air to fuel (A/F) ratio for internal combustion engines 74, 75

aliasing 70 Aloha protocol 205-206, 228 amperometric nitrate detector 94 analog signal processing interface 62, 64 analog to digital (A/D) conversion 22, 23, 35, 35 angle of arrival (AOA) 307 angles of incidence and reflection 39 angular frequency 33 anonymity 439 antennas 89-90 directional antennas 369 path selection 372, 372-373 pointing time 373 range extension 369-370 diversity 179 embedded antennas 90 gain 37 height 369 sidelobes 90 anti-aliasing filters 70 antibodies 95 aperture (f-number) of a camera 92 magnification and aperture size 92 Apple computers 480 applets 406 application program interfaces (APIs) 317 ARO schemes 161 array processing 225 articulation of network elements 368-369 cameras 370-371 detection with obstacles 371, 371-372 communications power efficiency 369 directional antennas 369 path selection 372, 372-373 pointing time 373 range extension 369-370 energy harvesting 376 following the sun 376, 376-377 mechanical issues 375 elevators 375-376 network impact 372 sensor diversity 373-375, 374, 468, 468-469

Index

511

ASICs 314 asymptotic equipartition property (AEP) 25 asymptotic error constant 504 atmospheric losses of radio signals 38 rain fading 39 atomicity of database transactions 332 autocorrelation function 19, 20, 20, 42, 43, 131, 132 autocovariance function 131 automotive EGO sensors 74-77, 75, 76 average data throughput 425 AWAIRS I nodes 429, 429-430, 431 bandwidth 154 baseband complex impulse response 40 baseband-equivalent 153 batteries 309, 323 lifetime 311 lithium batteries 310-311 rechargeable 311 Bayer sensors 93, 93 Bayes criterion 114 Bayes estimation 138–139 likelihood opinion pool 139 problems 128 Bayes rule 14 Bayes theorem 111 Bayesian networks 356-358 evidential and causal reasoning 358 beacon chips 487 beamforming 135, 135-136, 151, 265 near and far sources 249-250, 250 belief networks 357, 358, 366 Bell, Alexander Graham 84 Bellman-Ford algorithm 269 Bernoulli trials 12, 13 Bessel functions 16, 121 bias energy 71-72 bifurcation routing 237 binary entropy function 31 binary frequency shift keying (BFSK) 159 binary phase shift keying (BPSK) 153, 154 energy for near-ground communication 162 rake receiver 185 binary sequences 25 binary symmetric channel (BSC) 31, 32 binomial distribution 12-13, 32 biochemical signals 56-57 contours of equal concentration 56 Blumlein capacitance bridge 88 Bode plot 191 Boltzman's constant 38 Boolean expressions 334 Boolean logic 355 Boolean operators 334 Borg Collective 489-490 broadband noise level 65 broadcast channels 253, 253-254 efficiency of TDMA 254

Butterworth low-pass filter 35

cable transportation systems 386 Caesar code 459 calibration of instruments 383 temperature 383-384 cameras 370-371 detection with obstacles 371, 371-372 capacitive detection transducer 73 capacitive position sensors 87, 87-88, 88 capacity of communications systems 26-28 discrete communication 26 carbon microphones 84 carrier sense multiple access (CSMA) 206, 207 hidden and captured terminals 206, 206-207 CSMA/CD protocol 404 Cartesian product operator 335, 336 catalytic converters 74, 75 categories 367 causal reasoning 358 celestial measurements 279 cellular systems 182 network topology 229 reuse factor 7, 222 spatial reuse of frequencies 196, 196 traffic modeling 205 Central Limit Theorem 15 central node (CN) 261 election 248 single winner election algorithm 248-249 centroid of strongest signals 280 chain rule for entropy 26 channel probing 213-214 charge coupled devices (CCDs) 92, 93 chromatography 94 liquid, on a chip 95 ciphers 440-441 practical ciphers 441-443 relative complexity of discrete exponentials and logarithms 443 RSA system 443-444, 445 clocks, synchronization of 283-285 clock skew estimation 288-290 errors in synchronizing to UTC 290 post facto synchronization 289-290 reference broadcast system (RBS) 287-288 multihop 290 clustered networks 239 CMOS transistor pairs 312 power and delay 312-313 coaxial cable 49 code division multiple access (CDMA) 202, 202 sectorized antennas and single-cell capacity 208-209, 209 single-cell DS-CDMA capacity 202-203 coded modulation 159 coding gain 160 coherence time and velocity of a radio wave 43

512

Index

coherent data fusion 261 coherent detection of signals 116-119 pulse in Gaussian noise 123-124 collaborative multilateration 280-281 combining rule 344 communication range 383, 393, 424 complimentary code keying (CCK) 415 computer architecture 395-397, 399 distributed computing 403-404, 404 Ethernet network technology 404-406, 405 file abstraction-based middleware 406 Java virtual machine (JVM) 406 hardware/software codependencies 406-407 hardware design abstractions 407-408 information appliance interfaces 395 operations at interfaces 396-397 platform characteristics 419-424 platform interfaces 419 processor architecture 397-399, 398 memory hierarchy and speed 398 software architecture 400-403 condenser microphones 84 conditional entropy function 26 conjugate functions 18 connectivity in networks 231, 232-235, 268 coverage density and global connectivity 232-233 tesselation 232 SMACS protocol 234 consistency of database transactions 332 continuous random variables 14-15 continuous wave (CW) radars 47 convex optimizations 505-507 feasibility region for LP problem 506 convolution in the frequency domain of a function 18 time domain of a function 18 cookies 481 cooperative clusters 249 beamforming for near and far sources 249-250, 250 cooperative communication 264, 264-265 combining vs. single-user transmission 265 copyright 478 digital rights management 483-484 Coriolis force 81, 81, 82 correlation receiver 117 cosine filters 155 Costas loop 163, 190, 191 coverage area of a signal 58 coverage density in networks 232-233 tesselation 232 coverage holes for radio communications 47 Cramer-Rao (CR) bound 137, 285, 300, 302 Gaussian noise 137-138 three beacons 301 critical angle 39 cross-talk 64, 71, 72

crystal microphones 84 cumulative density function 33 cumulative distribution function (cdf) 33 Data Encryption Standard (DES) 441, 442 data fusion 123-127 rate of SNR increase with radius 124-125 data integrity 439, 457 authenticated service delivery 455-457 mobility and unreliable communications 456-457 telematics services 456 compression and compartmentalization 453-455 temperature fusion 454 data reliability in sensor networks 445-453 reliability mule 449 reliable multihop communication 448, 449 reliable temperature sensing 448 reputation system design parameters 452, 452-453 risk and redundancy 451 trust in temperature sensors 447 trustworthy organizations of unreliable elements 446 encryption 440 certification authorities 444 ciphers and their limitations 440-441 digital signatures and certificates 444, 445, 482 extensibility in security protocols 445 Internet security 445 practical ciphers 441-443 relative complexity of discrete exponentials and logarithms 443 RSA system 443-444, 445 data management 331, 361 database design principles data warehouses 340 deadlock resolution for the inconsistent analysis problem 337-338 distributed databases 338-339 layered architecture 333, 333-334 operations on databases 334-335 primitive operators 335-336 relational databases 331-332 replication of data for robustness 339 restrict, project and join operators 334-335, 335 higher-level reasoning 352 Bayesian networks 356-358 data mining 353 evidential and causal reasoning 358 language 359, 359-361 logic 353-356 profiling 353 sensor networks 340-342 adaptive data collection 349-350

More information

Index

513

as data compression engines 345, 345-346 fidelity and scaling 341, 341-342, 343 interest diffusion 346-349, 347 optimization of storage intervals 345-346 probabilistic data collection 342-344 standard vs. custom design 351, 351-352 storage with fusion 344, 344 TinyDB 352 variable sampling density 350, 350-351, 364 data mining 353, 483 profiling 353 data processing inequality 29, 29-30 database management system (DBS) 333 decision feedback equalizer (DFE) 168-172, 169 comparison with infinite length MMSE LEQ 170 - 171two-tap channels 171-172 decision regions for on-off signaling 122 decision trees 122 decision-directed loops 163-165 delay lock loop 164 early-late gate synchronizer 164 deductive logic 353, 355, 356 deductive arguments 354 delay lock loop 164 delay tracking loop 130 demand-driven routing 237 design of ENS 3-4 hierarchy 495-496 innovation 496-497 physical world 494-495 probabilities 495 scale 497-498 teamwork 498 detection and estimation theory for sources 109-110 hypothesis space 110 language identification and compression 110-111 detection delay 206 device drivers 401 difference operator 335 differential entropy 27 differentiation in the time domain of a function 17 Diffie-Hellman public key encryption system 442, 445 diffraction 39, 40 diffusion 56 contours of equal concentration 56 digital cameras 91-93, 312 magnification and aperture size 92 digital communications 152, 186 dispersive channels comparison of infinite length MMSE LEQ and DFE 170-171 decision feedback equalizer 168-172, 169 DFE for two-tap channel 171-172 echo cancelation 174, 174-175 effect of ISI on PAM 166, 166-167

line probing 173-174 MMSE criterion 168 OFDM 175-176 power and bit allocation in OFDM 176 precoding 172-173 zero forcing criterion 165, 165-168 dynamic channels 176-177 diversity 179-182 diversity-combining heuristic 179 gain with MR diversity combining 181 multipath fading 177-178 near-ground communication energy cost with fading 178 no coding, no diversity 183-184 simple SNR-based bit allocation 178-179 spread spectrum communications 183-186 time diversity in cellular systems 182 Gaussian channel 155 channel coding 159-161, 160 energy for near-ground communication 162 error probability 156-159 for 4-PAM 156-157 quadrature amplitude probability (QAM) 157, 157-159, 158 rate 2/3 parity check code 160, 161 signal characterization 152-155 basic system 153 Nyquist filters 154–155, 155 power spectrum for BPSK 153, 154 synchronization 162-163 decision-directed loops 163-165, 164 digital signatures and certificates 444, 445, 482 CAs 444 international identity digital certificate 482 digital to analog (D/A) conversion 23, 23, 35, 35 Dijkstra algorithm 270 dipole antennas 89 beam pattern 37, 58 Dirac comb 21, 167 direct current (DC) motors 375 direct sequence spread spectrum (DS-SS) 184, 184, 415 directed diffusion 241-242 path selection 241-242, 242, 271 sensor networks 252 sleeping nodes 246, 246 discrete dispersive channel 135 discrete multitone modulation (DMT) 175 discrete random variables 12 discrete-time random processes 131 dispersive channel 165 distance attenuation 41 distance vector protocols 236 distributed computing 403-404, 404 Ethernet network technology 404-406, 405 file abstraction-based middleware 406 Java virtual machine (JVM) 406

514

Index

distributed databases 338-339 catalog of entries 339 concurrency 338 naming of objects 339 optimization 338 replication of data 338, 339 robustness 339 divide operator 336 Doppler power spectrum 43, 59 Doppler spread 43 drift 65, 71 dropping probability 205 duality of a function 17 durability of database transactions 332 dynamic channel allocation (DCA) 209-211 dynamic microphones 84 dynamic modulation scaling 321 dynamic power and channel allocation (DPCA) 211, 211-213 dynamic source routing (DSR) 237-239, 271 dynamic voltage scaling (DVS) 313 earliest deadline first (EDF) 313-314 early-late gate synchronizer 164, 191 earthquakes 55 echo cancelation 174, 174-175 ecotones 388 effective isotropic radiated power (EIRP) 90 electrical angle 200 electromagnetic actuators 104 electron shot noise 96, 97 electronic nose 95 electrostatic actuators 103, 103 elevators 375-376 Em* environment 469-470 embedded network systems (ENS) design heuristics 3-4 enacted spaces 8 essential components 1 further information 10-11 general principles 1-3 generic network architecture 3 historical context 9-10 illustrative examples, habitat monitoring system 5-7, 6 node block diagram 2 remote monitoring 4-5 RFID 7-8, 488 enacted spaces 8 encryption of data 440 ciphers and their limitations 440-441 digital signatures and certificates 444, 445, 482 CAs 444 international identity digital certificate 482 Internet security 445 extensibility in security protocols 445 practical ciphers 441-443

relative complexity of discrete exponentials and logarithms 443 RSA system 443-444, 445 energy management 309, 325-326 communication relays 329 data fusion network 318 energy capacities per unit mass 310 per unit volume or area 310 energy consumption 311 communications 315-317 communications vs. processing energy costs 316-317 Gene's Law 314-315 integrated circuits 312-315 multihopping 316 power and delay in CMOS transistor pairs 312-313 radios 315, 316 sensors 311-312 energy efficiency trends in processors 314 energy harvesting 376, 419, 426 following the Sun 376, 376-377 energy optimization 317 adaptive fidelity 322 and increased lifetime 322-323 communications duty cycling 318-322, 319, 322 coping with inefficient MACs 320 dynamic modulation scaling 321 energy mule 324, 324-325 heterogeneous energy resources 323-325 processing location 317-318 wake-up and sleep cycle energy cost 319 ENS design principles 412 comparison of battery storage cells 418, 418, 419 microprocessor systems 413-414, 414 wireless transceiver systems 414, 415-416 low-power operation 423 node energy storage 417 linear networks 328 mechanical issues 375 elevators 375-376 minimum energy path 329 sources of energy 309-311 energy supply dimensions 310-311 energy metric computation 241 energy mule 324, 324-325 energy-constrained sensor networks 239 entropy and information 24-25 chain rule 26 conditional entropy function 26 joint entropy function 26 environmental monitoring 487 equal gain combining 180 equivalence (in logic) 355, 355 Erlang model 203, 203

Index

515

estimation problems 128 Ethernet network 404-406, 405 ethics 475-476 Euclidean distance 161 Euclidean distance propagation 297, 297-298 Euclidean norm 503 Euclid's algorithm 459 evidential reasoning 358 exhaust gas oxygen (EGO) sensors 74-77, 75, 76 experimental systems design 463, 474 design iteration 464-466 from laboratory to classroom 466 **NIMS 472** classroom 472-473 field deployment 473-474 treebots 472 prioritization 463-464 pre-NIMS objectives 464 project branching 471-472 simple communications system 467 simulations, tools, and testing 466-470 Em* environment 469-470 formal optimization 466-467 measuring rotation velocity 471 sensor diversity 468, 468-469 users in the design team 473 exponential backoff 405 f-number (aperture) of a camera 92 magnification and aperture size 92 fading of radio signals combination of fading effects 42 distance attenuation 41 in-building losses 44-45, 45 multipath fading 41 probability 41-42 shadow fading 41 feedback control 100, 100-102, 101, 102 comparison between open and closed loop accelerometer systems 102-103 feedback shift register 193 fibers, propagation of optical signals 50 field effect transistors (FETs) 98 noise 98 field of view 370 field programmable array (FPGA) 314 file abstraction-based middleware 406 Fisher information matrix 300, 301 flat networks 230 flicker (1/f) noise 96, 97 elimination 99 typical case 97-98 flicker noise corner frequency 65 flooding in networks 235, 235-236, 269, 269, 269 floor attenuation factor (FAF) 45 focal length of a lens 51, 91 forward error correction (FEC) 161 Fourier series 18, 148

Fourier transform 17 angular frequency 33 free space propagation 37 frequency coherence 59 frequency division multiple access (FDMA) 201, 202 frequency domain 17-18 frequency-hopped spread spectrum 183 frequency shift keying (FSK) 149, 415 frequency shifting of a function 17 Friis free space equation 60 gas phase composition sensors 74 gauge factor 85 Gaussian CEO 264 Gaussian channel communications 27-28, 28.155 channel coding 159-161, 160 energy for near-ground communication 162 rate 2/3 parity check code 160, 161 error probability 156-159 4-PAM systems 156, 156-157 QAM 157, 157-159, 158 Gaussian distribution 14, 15, 32 Gaussian noise binary choice 111-112 with cost functions 114 coherent detection of pulse 123-124 NP criterion 112-113 power of pulse sequence 129, 130 source coverage region 127 Gaussian O function 15, 15, 499-500 Gaussian rate distortion function 261 Gaussian waterfall 160 Gene's Law 314-315 genetic algorithms 507 geographic adaptive fidelity (GAF) in routing 251, 251 geometric factors affecting network localization and synchronization 299-302 well-conditioned reference node location geometries 300 geophones 311, 412 global connectivity of networks 232-233 tesselation 232 global positioning system (GPS) 277, 283 linearizing equations 305 propagation errors 299 timing offset 305 Gram-Schmitt process 115 Gray code 188, 188 ground reflection model 227 gyroscopes 71, 80, 81 microgyroscopes 84 rate gyroscope response to Earth's rotation 82 thermal noise equivalent rotation rate 83-84 torsional unbalance force 82

516	Inc
10	Inc

Index

habitat monitoring system at the James San Jacinto Mountains Reserve 5-7 Internet access 10 robotic elements 6 sensor deployments 6 Hamming distance 161 hardware abstraction layer (HAL) 430 hash functions 460 helper nodes 262, 262 adding a helper node to a network 263 Hermitian transposition 132 heterodyning (signal chopping) 99, 99, 100 heterogeneous energy resources 323-325 heuristics 507 hierarchical networks 230 hierarchical routing 239, 239-240 historical context of ENS 9-10 horns of a dilemma 354-355 Huygens' principle 39 hybrid admission policies 213-214 hydrophones 84 hypothesis space 110 image location 59 image sensor 412 inductive logic 356 analogy 356 generalization arguments 356 information theory asymptotic equipartition property (AEP) 25 Bayes estimation of signals in additive noise 138-139 likelihood opinion pool 139 binary sequences 25 capacity 26-28 discrete communication 26 data processing inequality 29, 29-30 entropy 24-25 multiple Gaussian channels 27-28, 28 mutual information 26 networks 252-253 adding a helper node 263 broadcast and multiple access channels 253, 253 - 254capacity and density 259 coherent data fusion 261 combining vs. single-user transmission 265 cooperative communication 264, 264-265 efficiency of TDMA 254 interference channels 254, 254-255 lossless source coding 256-257 rate distortion coding 261-264 relay channels 255, 255 relays with fourth power distance loss 256, 256 scalability of sensor networks 257, 257-260, 258.260 rate distortion coding 28-29

test channel 29 signal representation 24 infrared detectors 312 instruction cycle times 402 instruction set architecture (ISA) 395, 396 integrated circuits, energy consumption of EDF and DVS 313-314 Gene's Law 314-315 Moore's Law 312 power and delay in CMOS transistor pairs 312-313 integration in the time domain of a function 17 integrated capacitance bridge 88 intellectual property rights 478 comparison between USA and European Union 479 digital rights management 483-484 interest diffusion 346-349, 347 interest gradients 252 interference channels 254, 254-255 interference coupling 214-218 interference models 195-197 interference prediction 197, 197-198, 223 spatial reuse of frequencies in cellular systems 196, 196 international identity digital certificate 482 Internet 481 cookies 481 creation 479 data mining 483 digital rights management 483-484 information retrieval 338 international identity digital certificate 482 making the web pay 481-482 netiquette 481 network time protocol (NTP) 286, 303 network topology 230 privacy as property 484 routing addresses 237 security systems 445 extensibility in security protocols 445 shortest path routing algorithm 236, 236-237 transport control protocol/Internet protocol (TCP/IP) 244, 445, 479 Internet Engineering Task Force (IETF) 479 interrupt operation 402, 402, 403 interrupt service routine (ISR) 402 intersect operator 336 intersymbol interference (ISI) 165, 166, 169 effect on binary pulse amplitude modulation (PAM) 166, 166-167 inverse fast Fourier transfrom (IFFT) 175 ionosphere, refraction of radio signals 46 isolation of database transactions 332

jam signal 405 Java virtual machine (JVM) 406 jitter of gyroscopes 71

Index

517

Johnson noise 64, 96 channel resistance 98 input-referred 98 join operator 334, 336 joint distribution 358 joint entropy function 26 knife-edge diffraction 40 laminar flow 56 contours of equal concentration 56 language 359, 359-361 identification and compression 110-111 Laplace transform 189 lasers 51 latency and congestion in networks queues 242-245, 243 M/M/1 queue 243-244 layered architecture of databases 333, 333-334 least interference algorithm (LIA) 210, 210, 234 least mean square (LMS) algorithm 136 least squares methods 505 estimation 131-137 lens assemblies in cameras 91 likelihood opinion pool 139 likelihood ratio test (LRT) 111 line probing 173-174 linear convergence 504 linear equalizer 133, 134-135 linear feedback shift register 226 linear programming 506 linear systems 18 linearity of a function 17 link-state protocols 236 Linux operating system 396, 402, 422 lithium batteries 310-311 Little's Theorem 227 local area networks (LANs) 45 local computing requirements 411 logic 353-356 horns of a dilemma 354-355 lognormal distribution 32 lossless source coding 256-257 lossy compression 26 low-noise amplifiers (LNAs) 315 low-power wireless integrated microsensors (LWIM) 427-428, 428 low-pass loop filter 190 M/M/1 queue 243-244 magnetometers 90-91 detection of objects 91 majority logic combining 125-126 Markov chains 30, 243 Mars to Earth communications 46 mass spectrometry 94 matrix norms 503, 504

maximal ratio (MR) combining 123, 125-126, 180, 181.193.224 gain with MR diversity combining 181 maximum a posteriori (MAP) criterion 111 maximum likelihood (ML) criterion 111 maximum likelihood sequence estimation (MLSE) 173 Maxwell's equations 40 mean of random variables 14 mean square error (MSE) 34 medical applications of ENS 489 medium access control (MAC) protocols 177, 201, 218.219 coping with inefficiency 320 low-energy design principles 219 memory management 397 memory management unit (MMU) 400, 401 microelectromechanical systems (MEMS) 10, 72 gyroscope 81 pressure transducer 72 microgyroscopes 84 microphones 84, 311 middleware 404, 406 file abstraction-based middleware 406 minimum mean square error (MMSE) 133, 165, 168, 182 comparison of infinite length MMSE LEQ with DFE 170-171 mobile ad hoc networks (MANETs) 229, 235 mobile and static nodes 368, 389-390 articulation 368-369 cameras 370-371 communications power efficiency 369 detection with obstacles 371, 371-372 directional antennas 369 energy harvesting 376 following the Sun 376, 376-377 mechanical issues 375 network impact 372 path selection with directional antennas 372, 372-373 pointing time for directional antennas 373 range extension from directional antennas 369-370 sensor diversity 373-375, 374, 468, 468-469 infrastructure-assisted mobility communication at elevation 386-387 exploiting gaps 387, 387-388, 388 mobility costs 384 on cable transportation systems 386 networked info-mechanical systems (NIMS) 385-389.386 system ecology components 389 transportation methods and costs 384-385 interaction 377 adaptive resource deployment 378-383 communicate or carry? 382, 382-383, 383, 393

Max quantizer 32

518

Index

mobile and static nodes (cont.) dungeons and dragons example 380-381, 381 obstructions 380, 380, 381, 393 robot ecologies 377-378 temperature calibration 383-384 triggering vs. searching 379, 379 modus tollens argument 354 monoclonal arrays of cells 95 monopole antennas 89 mood cars 486 Moore's Law 9, 312, 315 motes, dust, and fabrics 430-432 μ -law quantizer 23–24 multihopping 316, 448, 449 multipath fading 41, 41, 177-178 near-ground communication energy cost 178 simple SNR-based bit allocation 178-179 multipath intensity profile 42 multipath interference 192 antenna array adaptation 215-216, 216 multipath routing 237 multiple access channels 253, 253-254 efficiency of TDMA 254 multiple access communications 195, 219-220 basic techniques 201 Aloha protocol 205-206, 228 carrier sense multiple access (CSMA) 206 frequency, time, and code division multiple access 201-203, 202 hidden and captured terminals 206, 206-207 reservations 207 single-cell DS-CDMA capacity 202-203 statistical multiplexing 204 traffic modeling 203, 203-205 heterogeneous networks 218-219 interference 207 adaptive antennas 214 antenna array adaptation in multipath interference 215-216, 216 channel probing 213-214 dynamic channel allocation (DCA) 209-211 dynamic power and channel allocation (DPCA) 211, 211-213 hybrid admission policies 213-214 interference averaging 208 interference avoidance 208-209 interference coupling 214-218 least interference algorithm (LIA) 210, 210 sectorized antennas and single-cell capacity 208-209, 209 shadowing tails and coding 208 space division multiple access (SDMA) 214 two-user power control 211-212, 212 multiple input, multiple output (MIMO) systems 181, 223 multiple source estimation 195, 219-220 interference models 195-197 interference prediction 197, 197-198, 223

spatial reuse of frequencies in cellular systems 196, 196 source separation 198, 198-200 bandwidth and beam direction 199-200 node density 201 multiplication in the frequency domain of a function 18 multiplication in the time domain of a function 18 multiuser detection (MUD) 203 multiwinner election (MWE) 249 mutations 507 mutual information 26 nanotechnology 10 navigation instruments 282-283 near-ground radio propagation 46, 60, 60 negative acknowledgement (NACK) 205, 206 Nernst equation 75 netiquette 481 network position services 274, 291-292, 303-304 error sources 298 CR bound for three beacons 301 geometric factors 299-302 propagation effects 298-299 software-induced delays 302-303 well-conditioned reference node location geometries 300 location principles 274 collaborative multilateration 280-281 computation from two VOR measurements 276 effect of angle measurement uncertainty 275, 275navigation and survey instruments 282-283 ranging in two dimensions 278, 278-279 source localization 281-282 time difference of arrival (TDOA) 279 time of arrival (TOA) 276-279 triangulation 274-275, 275 VHF omnidirectional ranging (VOR) 275 - 276weighted centroid computation 279-280 network time of arrival 292-295 location of fourth node in a plane 296, 296 position estimation without ranging 292-293, 293 reference propagation 296-297 Euclidean distance propagation 297, 297-298 relative coordinate system 294 source locations 298 TOA for third point 291, 292 network synchronization 274, 283, 303-304 basic principles 285-286 clock skew estimation 288-290 errors in synchronizing to UTC 290-291 post facto synchronization 289-290 reference broadcast system 287-288

Index

519

error sources 298 CR bound for three beacons 301 geometric factors 299-302 propagation effects 298-299 software-induced delays 302-303 well-conditioned reference node location geometries 300 phase error 285 two clocks 283-285 network time protocol (NTP) 286, 303 networked info-mechanical systems (NIMS) 385-389, 386, 433, 434 classroom 472-473 communication at elevation 386-387 exploiting gaps 387, 387-388, 388 field deployment 473-474 implementation 472 mobility costs on cable transportation systems 386 pre-NIMS objectives 464 system ecology components 389 treebots 472 networks 229, 265-266 data reliability in sensor networks 445-453 reliability mule 449 reliable multihop communication 448, 449 reliable temperature sensing 448 reputation system design parameters 452, 452-453 risk and redundancy 451 trust in temperature sensors 447 trustworthy organizations of unreliable elements 446 heterogeneous networks 433-434 personnel detection 434-435 information theory 252-253 adding a helper node 263 broadcast and multiple access channels 253, 253-254 capacity and density 259 coherent data fusion 261 combining vs. single-user transmission 265 cooperative communication 264, 264-265 efficiency of TDMA 254 interference channels 254, 254-255 lossless source coding 256-257 rate distortion coding 261-264 relay channels 255, 255 relays with fourth power distance loss 256, 256 scalability of sensor networks 257, 257-260, 258, 260 interaction between signal processing and networking in sensor networks 246-248, 247, 248 adaptive cooperative network formation 248-249 beamforming for near and far sources 249–250, 250

directed diffusion 252 geographic adaptive fidelity in routing 251, 251 predefined cooperative clusters 249 single winner election algorithm 248-249 variable node alertness 250-251 latency and congestion directed diffusion with sleeping nodes 246, 246 M/M/1 queue 243-244 other sources of delay 245-246 queues 242-245, 243 routing demand-driven routing 237 directed diffusion 241-242 for path selection 241-242, 242, 271 dynamic source routing (DSR) 271 and ad hoc on-demand distance vector (AODV) routing 237-239 energy metric computation 241 flooding 235, 235-236, 269, 269 hierarchical routing 239, 239-240 overlapping spanning trees 240, 240-241 shortest path algorithm 236-237 self-organization basic tasks 231-232 connectivity 232-235 coverage density and global connectivity 232 - 233frame structure 231 SMACS protocol 234 tesselation 232 three-tier networks 462 topology 229-231 ad hoc layouts 268 basic layouts 230 clustered and overlay networks 230 simple layouts 270 tree lavouts 268 Newton's iterative method for roots 501, 504 Neyman-Pearson (NP) criterion 112, 345 target in Gaussian noise 112-113 nitrate detector 94 node architecture 394, 435 computing platform architecture 395-397, 399 abstraction layers 396 distributed computing 403-404, 404 Ethernet network technology 404-406, 405 file abstraction-based middleware 406 hardware design abstractions 407-408 hardware/software co-dependencies 406-407 information appliance interfaces 395 Java virtual machine (JVM) 406 memory hierarchy and speed 398 operations at interfaces 396-397 processor architecture 397-399, 398 software architecture 400-403 ENS design principles 408

520

Index

node architecture (cont.) comparison of: battery storage cells 418, 418, 419 microprocessor systems 413-414, 414; wireless transceiver systems 414, 415-416 computing platform characteristics 414, 419-424 energy requirements 412 information acquisition 410-411 information transport 411-412 network characteristics 424-426 platform structure 417-419 primary requirements 409 system logistics 426-427 sensor node design 427 AWAIRS I nodes 429, 429-430, 431 dedicated hardware solutions without operating systems 427 fully featured operating systems 432 heterogeneous networks 433-434 low-power wireless integrated microsensors (LWIM) 427-428, 428 NIMS 433, 434 passive radio frequency identification (RFID) tags 427 personnel detection 434-435 PicoWINS 428-429 real-time operating systems 429 sensor motes, dust, and fabrics 430-432 WINS NG 432, 432-433, 433 node density 201 noise figure 58 noise signals 63, 64, 65 noise-equivalent signal (NES) level 64, 66 non-coherent detection of signals 119-123 noncoherent combining 125 non-convex optimizations 507-508 non-line-of-sight (NLOS) propagation 298, 299 numerical analysis 501-505 Nyquist band 154 Nyquist criterion 165, 167 Nyquist filters 154-155, 155 Nyquist interval 167 Nyquist rate 21 observations period lifetime 410 spatial density 410 temporal frequency 410 volume 410 occlusion geometry 392 offset 71 one-phase pull diffusion 348 one-time pad ciphers 440 open code software 482-483 operating systems 401, 402, 403, 422 nodes with fully featured operating systems 432 nodes with real-time operating systems 429 AWAIRS I nodes 429, 429-430, 431

NIMS 433, 434 sensor motes, dust, and fabrics 430-432 WINS NG 432, 432-433, 433 optical communication systems 372 optical signal propagation 50-52 aligned optics 51-52 optimality criterion 134 optimization strategies 501 convex optimizations 505-507 feasibility region for LP problem 506 non-convex optimizations 507-508 numerical analysis 501-505 orthogonal frequency division multiplexing (OFDM) 175-176, 182 power and bit allocation 176 overlapping spanning trees 240, 240-241 energy metric computation 241 oxygen molecules, atmospheric losses of radio signals 38 packet data communication 205, 218, 228 pan/zoom/tilt (PZT) mechanisms for cameras 370 panning of cameras 370 parallelism 313 parity check codes 160, 161 Parseval relation 18, 66, 67 Parseval Theorem 66 partition attenuation factors (PAF) 45 passive RFID tags 7, 427 passive sensors 311 patch antennas 89 patents 478 path losses for radio signals 44 peak data throughput 425 peak-to-average power ratio (PAR) reduction 175 peer-to-peer systems 485-487 personal profiling 489 personnel detection 434-435 phase error 285 phase lock loop (PLL) 131, 162, 163, 189 low-pass loop filter 190 phase noise model 190 photoconductivity 92 photodetectors 311 photodiodes 92 photoelectric effect 92 photoemission 92 photon shot noise 64 photovoltaic effect 92 PicoWINS 428-429 piezoelectric strain coefficient 86 piezoelectric transducers 86, 86 vibration accelerometer 86-87, 87 piezoresistive strain/force transducers 84-85, 85 X-ducer 85, 85 pixel density of digital cameras 93 planar drive actuator 103 PN code synchronism 184

Index

521

Poisson distribution 16 pollution from internal combustion engines 74, 75 position sensors 87, 87-88, 88 post facto synchronization 289-290 potentiometry 95 power of a wave with spherical propagation 36 power spectral density (psd) 66, 67 measurement 70-71 precoding 172-173 pressure sensor system 100, 101 pressure sensors 72, 72–73 responsivity 73 primitive database operators 335-336 privacy as property 484 beacon chips 487 concerns 8 probabilistic data collection 342-344 adaptive fidelity 343 data naming 343 hierarchy 343 in-network processing 343 node activation and clustering 343 storage with fusion 344, 344 probability density function (pdf) 14, 33 probability theory binomial distribution 12-13 conditional distribution 13-14 continuous random variables 14-15 discrete random variables 12 Poisson distribution 16 processing gain 184, 193 processor architecture 397-399, 398 memory hierarchy and speed 398 project operator 334, 335 proof by induction 356 proof mass acceleration 78 propagation delay 206 pseudonoise (PN) sequence 183, 192 public key ciphers 441, 442, 481 digital signatures and certificates 444, 445 certification authorities 444 pulse amplitude modulation (PAM) 156, 156 - 157effect of inter-symbol interference (ISI) 166, 166-167 low-pass equivalent representation 187 pulsed radars 47, 283 pulse-width-modulated (PWM) methods 104 push diffusion 348 *Q* function 15, *15*, 499–**500** quadratic convergence 504 quadrature amplitude probability (QAM) 157, 157-159, 158 quantization 22-24, 23 μ -law quantizer 23–24

radar 47-48, 199, 276, 277 radio frequency identification (RFID) tags 7-8, 427, 488 radio signal propagation 44-49 across mountains, within cities and regional coverage 47 in-building losses 44-45, 45 Mars to Earth communications 46 statistical model parameters 44 wired vs. wireless propagation 49 radios, energy consumption of 315 multihopping 316 rain fading of signals 39 rate distortion coding 28-29 test channel 29 rate distortion function 29 rate of convergence 503 rationalism 9 Rayleigh distribution 16, 31, 41 Rayleigh fading 177, 178 rechargeable batteries 311 redundancy in networks 451 Reed-Solomon (RS) codes 339 reference broadcast system (RBS) 287-288 multihop 290 reference propagation 296-297 Euclidean distance propagation 297, 297-298 relative coordinate system 294 reflection 39 refraction 39 refraction errors 299 regulation of technologies within liberal democracies 477-479 creation of the Internet 479 information technology code as regulator 480-481 data mining 483 digital rights management 483-484 international identity digital certificate 482 making the web pay 481-482 open vs. proprietary code 482-483 persistence of design 480 privacy as property 484 intellectual property rights 478 comparison between USA and European Union 479 relational databases 331-332 components 334 operations on databases 334-335 primitive operators 335-336 restrict, project, and join 334-335 updates 336-337 deadlock resolution for the inconsistent analysis problem 337-338 relative coordinate system 294 relay channels 255, 255

relays with 4th power distance loss 256, 256 reliability mule 449

quantization noise 98

522

Index

remote monitoring 4-5 reputation systems 451 design parameters 452, 452-453 reservation protocols 207 resistive gas sensors 77 responsivity of sensors 64 accelerometer 68, 78 pressure sensors 73 restrict (select) operator 334, 335 ribbon microphones 84 Rice distribution 16, 34, 41 Rijndael encryption algorithm 442 robots 377-378, 384 robotic monitoring system 488 rotary electric motors 375 route error (RERR) messages 239 route reply packet (RREP) 238 route request (RREQ) packet 238, 238 RSA encryption system 443-444, 445 rule of twos 496, 497 sampling theorem 20-22, 21 square waves 22 satellite communications systems 44 link budget 38, 58 scalability of sensor networks 340 adaptive data collection 349-350 variable sampling density 350, 350-351, 364 data compression engines 345, 345-346 optimization of storage intervals in two-level networks 345-346 fidelity and scaling 341, 341-342, 343 interest diffusion 346-349, 347 probabilistic data collection 342-344 storage with fusion 344, 344 standard vs. custom design 351, 351-352 TinyDB 352 science fiction and society 488-489 Borg Collective 489-490 enacted ethical shopping 488-489 medical applications 489 personal profiling 489 secret key ciphers 441, 442 sectorized antennas and single-cell capacity 208-209, 209 secure socket layer (SSL) 445, 481 security surveillance 487-488 robotic monitoring system 488 seismic signal propagation 52-56 location of geological layers 55, 55, 59 seismometers 55 select (restrict) operator 334, 335 self-organizing medium access control for sensor networks (SMACS) protocol 234 sensing signal resolution 410 sensing temporal resolution 411 sensitivity of sensors 64, 69, 70 accelerometer 68-70

power spectral density (psd) 66-68 measurement 70-71 sensor networks 239 cooperative communication 264, 264-265 combining vs. single-user transmission 265 data reliability 445-453 reliability mule 449 reliable multihop communication 448, 449 reliable temperature sensing 448 reputation system design parameters 452, 452-453 risk and redundancy 451 trust in temperature sensors 447 trustworthy organizations of unreliable elements 446 interaction between signal processing and networking 246-248, 247, 248 adaptive cooperative network formation 248-249 beamforming for near and far sources 249-250, 250 directed diffusion 252 geographic adaptive fidelity in routing 251, 251 predefined cooperative clusters 249 single winner election algorithm 248-249 variable node alertness 250-251 lossless source coding 256-257 rate distortion coding 261-264 adding a helper node 263 coherent data fusion 261 scalability 257, 257-260, 258, 260, 340 adaptive data collection 349-351, 350, 364 capacity and density 259 data compression engines 345, 345-346 fidelity and scaling 341, 341-342, 343 interest diffusion 346-349, 347 optimization of storage intervals in two-level networks 345-346 probabilistic data collection 342-344 standard vs. custom design 351, 351-352 storage with fusion 344, 344 TinyDB 352 sensor system actuation 411, 416 sensor system calibration 411 sensors 61, 105-106 actuators for microsensor systems 103, 103-104 computation of force and deflection for accelerometer systems 104 arrays 461 calibration 104-105 chemical and biochemical sensors 93-96 amperometric nitrate detector 94 electronic nose 95 liquid chromatography on a chip 95 deployment 225 dimensions 417 diversity in articulated systems 373-375, 374, 468, 468-469

Index

523

electromagnetic transducers 88-89 antennas 89-90 digital cameras 91-93 magnetometers 90-91 electronic noise 96 sources 96-98 stability of measurement circuits 98-100, 99 energy consumption 311-312 environmental sensors 72 automotive exhaust gas oxygen (EGO) sensors 74-77, 75, 76 gas phase composition sensors 74 pressure sensors 72, 72-73 feedback control methods for reducing system errors 100, 100-102, 101, 102 comparison between open and closed loop accelerometer systems 102-103 ideal system architecture 61-63 closed loop 62 open loop 62 motion and force sensors 77-78 acceleration sensors (accelerometers) 78, 78 - 80capacitive position sensors 87, 87-88, 88 microphones 84 piezoelectric transducers 86, 86 piezoresistive strain/force transducers 84-85, 85 rotation and rotation rate sensors 80-84, 81 node design 427 AWAIRS I nodes 429, 429-430, 431 dedicated hardware solutions without operating systems 427 fully featured operating systems 432 heterogeneous networks 433-434 low-power wireless integrated microsensors (LWIM) 427-428, 428 NIMS 433, 434 passive radio frequency identification (RFID) tags 427 personnel detection 434-435 PicoWINS 428-429 real-time operating systems 429 sensor motes, dust, and fabrics 430-432 WINS NG 432, 432-433, 433 non-ideal system operation 63, 63-64 standard figures of merit 64-66 accelerometer sensitivity 68-70 drift and offset 71 interference and cross-talk 71 measuring power spectral density 70-71 sensitivity power spectral density 66-68 transducer bias energy 71-72 system administration 426 system structure 417 servo motors 375 shadow fading 41 shadowing 40, 58

shadowing tails 208 Shannon channel capacity 27, 160, 162, 181 Shannon, Claude 24, 25 Shannon-Hartley sampling theorem 21, 21 shortest path routing algorithm 236-237 Internet 236, 236-237 signal chopping (heterodyning) 99, 99, 100 signal propagation 36, 57 acoustic and seismic signals 52-56, 55 acoustic propagation velocity 53 acoustic properties of concert halls 54, 54 effects of relative humidity 53 effects of wind and motion on propagation velocity 53-54, 54 location of geological layers 55, 55, 59 speed of sound in various media 53 biochemical signals 56-57 contours of equal concentration 56 optical signals 50-52 aligned optics 51-52 radio signals 44-49 across mountains, within cities and regional coverage 47 in-building losses 44-45, 45 Mars to Earth communications 46 radar 47–48 wired vs. wireless propagation 49 wave propagation phenomena 36-43 coherence time and velocity 43 link budget for satellite communications system 38, 58 signal representation 12, 30, 114-116, 115, 116 alternative basis functions 116, 117 information theory 24 asymptotic equipartition property (AEP) 25 binary sequences 25 capacity 26-28 data processing inequality 29, 29-30 discrete communication 26 entropy 24-25 multiple Gaussian channels 27-28, 28 mutual information 26 rate distortion coding 28-29, 29 probability theory binomial distribution 12-13 conditional distribution 13-14 continuous random variables 14-15 discrete random variables 12 Poisson distribution 16 propagation characteristics 425 stochastic processes colored noise 19 frequency domain 17-18 linear systems 18 quantization 22-24, 23 representation 18-20 sampled square wave 22 sampling theorem 20-22, 21

524

Index

signal to interference ratio (SIR) 196, 209, 211, 213 signal to noise ratio (SNR) 27, 37, 128-129 beamforming 249 bit allocation for multipath fading 178-179 central node (CN) election 248 link budget for satellite communications system 38, 58 network cooperation 142-143 data fusion algorithm 142 weighted centroid computation 280 simulations 466-470 Em* environment 469-470 formal optimization 466-467 measuring rotation velocity 471 single winner election algorithm 248-249 single input, single output (SISO) systems 181 sleeping nodes 246, 246 Slepian-Wolf encoding theorem 256, 273, 453 social aspects of ENS 475, 492 regulation of information technology code as regulator 480-481 data mining 483 digital rights management 483-484 international identity digital certificate 482 making the web pay 481-482 open vs. proprietary code 482-483 persistence of design 480 privacy as property 484 regulation of physical world by information technology 485 benefits 492 Borg Collective 489-490 embedded responsibility 490-491 environmental monitoring 487 medical applications 489 mood cars 486 peer to peer systems 485-487 personal profiling 489 privacy and beacon chips 487 robotic monitoring system 488 science fiction and society 488-489 security 487-488 shopping 488-489 technology and society comparison between USA and European Union 479 creation of the Internet 479 ethics 475-476 intellectual property rights 478 liberal democracy 476-477 regulatory processes 477-479 software architecture 400-403 software-induced delays 302-303 solar cells 311, 324 solar energy 376, 376-377, 426 sonar 59, 276, 277 submarine tracking 59 sources 109, 146-147

detection and estimation theory 109-110 hypothesis space 110 language identification and compression 110-111 detection of signals in additive noise binary choice in Gaussian noise: 111-112, 112; with cost functions 114 coherent detection: 116-119, 117, 119; of pulse in Gaussian noise 123-124 coverage region for source in Gaussian noise 127 data fusion 123-127 density vs. fusion 126 detection criteria 111-114 non-coherent combining 125 non-coherent detection 119-123, 121 NP criterion for target in Gaussian noise 112-113 rate of SNR increase with data fusion radius 124-125 selection, maximal ratio and majority logic combining 125-126 sequential detection 113-114 signal representation 114-116 signals of unknown phase 121-122, 122 estimation of signals in additive noise beamforming 135, 135-136, 151 correlation matrix for a sinusoid 132-133 Cramer-Rao (CR) bound 137 in Gaussian noise 137-138 estimation criteria 127-128, 128 information theory and Bayes estimation 138-139, 139 least squares estimation 131-137 linear equalizer 133, 134-135 phase estimation 129-130, 131 plane waves 136 power of pulse sequence in Gaussian noise 129, 130 SNR 128-129 hierarchical detection and identification systems 139-146 density, coverage and propagation laws 144 local and distant sources 140 multiple cameras with obstructions 144-145, 145 signal locations 141 signal processing hierarchy 141 signal strength variations 140-141, 141 SNR-based network cooperation 142, 142 - 143localization 272, 281-282, 298 space division multiple access (SDMA) 214 spanning trees 240, 240-241, 271 energy metric computation 241 spectrum analyzers 70 speed of a photographic film 91 SQL (structured query language) 332, 333

Index

525

standard deviation of random variables 14 star networks 229, 230 statistical multiplexing 204 stepper motors 375 stochastic processes frequency domain 17-18 linear systems 18 sampling theorem 20-22, 21 sampled square wave 22 storage with fusion 344, 344 strict sense stationary (SSS) processes 20 submarine tracking 59 substitution ciphers 440 survey instruments 282-283 swelling of polymers 95 symbol-by-symbol phase estimation 284 system calls 403 system logistics 426-427 table-driven routing methods 237 tag reading 7 tautology 355, 355 Taylor's Theorem 277, 350, 365 telematics services 456 telephone wire, propagation characteristics 48 telescopes 92 temperature calibration 383-384 temperature sensors 447, 448 tesselation 232 thermal drift 79 thermal noise equivalent acceleration (TNEA) 80 thermal noise limit 80 thermistors 412 thermodynamic noise 64 thermomechanical noise accelerometers 79 gyroscopes 83 thin lens focusing 50 tilting of cameras 370 time difference of arrival (TDOA) location methods 279 three-dimensional space 307 two-dimensional space 306 time diversity in cellular systems 182 time division multiple access (TDMA) 201, 202, 209 efficiency 254 sectorized antennas and single-cell capacity 208-209, 209 time of arrival (TOA) location methods 276-279 error reduction 306 low-cost clocks 306 networks 292-295 position estimation without ranging 292-293, 293 ranging in two dimensions 278, 278-279 third point location 291, 292 time scaling of a function 17 time shifting of a function 17

time-hopping spread spectrum (TH-SS) 185 time-variant transfer function 42 timing errors 285 TinyDB 352 Tomlinson-Harashima (TH) precoding 172, 172, 173 torque 375 torsional unbalance force 82, 82, 83 total internal reflection 39 traffic modeling 203, 203-205 transducer bias energy 71-72 transducer scaling 79 transducers 61 transistor amplifier front end noise 97 transponders 277 transport control protocol/internet protocol (TCP/ IP) 244, 445, 479 transportation methods and costs 384-385 traveling salesman problem 330 treebots 472 triangular waves 35 triangulation 274-275, 275 effect of angle measurement uncertainty 275, 275 Tsvet, Mikhail S. 95 two-phase pull diffusion 348

ultrawide band (UWB) communication 185 unicity distance 459 uniform distribution 14 uniform quantizer 34 union operator 335 updates of databases 336–337 access locking 336, **337** deadlock resolution 337–338 inconsistent analysis problem 336, 337–338 locking protocol 337 lost update problem 336 uncommitted dependency problem 336

variance of random variables 14 vector norms 503 VHF omnidirectional ranging (VOR) 275–276 computation of location from two measurements 276 vibration accelerometer 86–87, 87 Virginère codes 459 voltage-controlled clock (VCC) 164 voltage-controlled oscillator (VCO) 130 Von Neumann, John 397 Von Neumann architecture 395

water flowing through soil 56 water vapor, atmospheric losses of radio signals 38 wave propagation phenomena 36–43 link budget for satellite communications system 38, 58 waveguides 40

526

Index

weak law of large numbers 25 web *see* Internet weighted centroid computation 279–280, 307 whip antennas 89 wide-sense stationary (WSS) processes 20, 43, 131 frequency coherence 59 Wien, Wilhelm 94 Wiener filters 134, 136 Wiener–Hopf equations 134 WINS NG *432*, 432–433, *433* wired vs. wireless propagation of radio signals 49 words, meaning of 359 World Wide Web *see* Internet

X-ducer 85, 85

Zero-forcing criterion *165*, 165–168 effect of ISI on PAM *166*, 166–167 zoom lenses 92 zooming of cameras 370