9 Data link layer 253
9.1 General 253
9.2 Data link layer data service access point 315
9.3 Data frames and acknowledgements 317
9.4 Data link layer management information base 339
9.5 Data link layer methods 381
9.6 Data link layer alerts 383
10 Network layer 386
10.1 General 386
10.2 Network layer functionality overview 386
10.3 Network layer data services 404
10.4 Network layer management object 406
10.5 Network layer protocol data unit formats 413
11 Transport layer 421
11.1 General 421
11.2 Transport layer reference model 421
11.3 Transport security sub-layer 422
11.4 Transport data entity 422
11.5 Transport layer protocol data unit encoding 426
11.6 Transport layer model 428
12 Application layer 438
12.1 General 438
12.2 Energy considerations 438
12.3 Legacy control system considerations 438
12.4 Introduction to object-oriented modeling 439
12.5 Object model 441
12.6 Object attribute model 442
12.7 Method model 444
12.8 Alert model 444
12.9 Alarm state model 445
12.10 Event state model 446
12.11 Alert reporting 446
12.12 Communication interaction model 448
12.13 Application layer addressing 457
12.14 Management objects 461
12.15 User objects 461
12.16 Data types 491
12.17 Application services provided by application sub-layer 497
12.18 Application layer flow use to lower layer services 530
12.19 Application layer management 531
12.20 Process control industry standard data structures 551
12.21 Additional tables 554
12.22 Coding 555
12.23 Syntax 574
12.24 Detailed coding examples (INFORMATIVE) 587
13 Gateway 589
13.1 General 589
13.2 Service access point 593

13.3 Protocol 632
14 Provisioning 651
14.1 General 651
14.2 Terms and definitions 651
14.3 Provisioning procedures 653
14.4 Pre-installed symmetric keys 653
14.5 Provisioning using out-of-band mechanisms 654
14.6 Provisioning networks 654
14.7 State transition diagrams 656
14.8 Device management application protocol objects for provisioning 661
14.9 Management objects 663
14.10 Device provisioning service object 668
14.11 Provisioning functions (INFORMATIVE) 677
Annex A (INFORMATIVE) Protocol implementation conformance statement proforma 680
A.1 Introduction 680
A.2 System 682
A.3 System management 685
A.4 Security manager 688
A.5 Physical layer 689
A.6 Data link layer 691
A.7 Network layer 692
A.8 Transport layer 694
A.9 Application layer 695
A.10 Gateway 703
A.11 Provisioning 705
Annex B (NORMATIVE) Role profiles 707
B.1 Introduction 707
B.2 System 708
B.3 System manager 708
B.4 Security manager 708
B.5 Physical layer 709
B.6 Data link layer 710
B.7 Network layer 715
B.8 Transport layer 716
B.9 Application layer 716
B.10 Gateway 716
B.11 Provisioning 717
Annex C (INFORMATIVE) Background information 718
C.1 Industrial needs 718
C.2 Usage classes 718
C.3 Other uploading and downloading- alarms (human or automated action) 719
C.4 The open systems interconnection basic reference model 720
Annex D (NORMATIVE) Configuration defaults 723
D.1 General 723
D.2 System management 723
D.3 Security 724
D.4 Data link layer 724
D.5 Network layer 725

D.6 Transport layer 726
D.7 Application layer 726
D.8 Gateway 728
D.9 Provisioning 728
Annex E (INFORMATIVE) Use of backbone networks 730
E.1 General 730
E.2 Recommended characteristics 730
E.3 Internet protocol backbones 730
Annex F (NORMATIVE) Basic security concepts – Notation and representation 732
F.1 Strings and string operations 732
F.2 Integers, octets, and their representation 732
F.3 Entities 732
Annex G (INFORMATIVE) Using certificate chains for over-the-air provisioning 733
Annex H (NORMATIVE) Security building blocks 734
H.1 Symmetric key cryptographic building blocks 734
H.2 Asymmetric key cryptographic building blocks 735
H.3 Keying information 735
H.4 Key agreement schemes 736
H.5 Keying information schemes 737
H.6 Challenge domain parameter generation and validation 738
H.7 Challenge validation primitive 738
H.8 Secret key generation (SKG) primitive 739
H.9 Block-cipher-based cryptographic hash function 739
H.10 Elliptic curve cryptography manual certificate scheme 740
Annex I (INFORMATIVE) Definition templates 743
I.1 Object type template 743
I.2 Standard object attributes template 743
I.3 Standard object methods 744
I.4 Standard object alert reporting template 745
I.5 Data structure definition 746
Annex J (INFORMATIVE) Operations on attributes 747
J.1 Operations on attributes 747
J.2 Synchronized cutover 750
Annex K (NORMATIVE) Standard object types 751
Annex L (INFORMATIVE) Standard data types 757
Annex M (NORMATIVE) Protocol identification values 759
Annex N (INFORMATIVE) Tunneling and native object mapping 760
N.1 Overview 760
N.2 Tunneling 760
N.3 Foreign protocol application communication 760
N.4 Native object mapping 761
N.5 Tunneling and native object mapping tradeoffs 761
Annex O (INFORMATIVE) Generic protocol translation 762
O.1 Overview 762
O.2 Publish 762
O.3 Subscribe 763
O.4 Client 763

O.5 Server 764
Annex P (INFORMATIVE) Gateway service access point adaptations for this standard 766
P.1 General 766
P.2 Parameters 766
P.3 Session 766
P.4 Lease 766
P.5 Device list report 767
P.6 Topology report 767
P.7 Schedule report 767
P.8 Device health report 767
P.9 Neighbor health report 767
P.10 Network health report 767
P.11 Time 767
P.12 Client/server 767
P.13 Publish/subscribe 768
P.14 Bulk transfer 769
P.15 Alert 769
P.16 Gateway configuration 769
P.17 Device configuration 769
Annex Q (INFORMATIVE) Gateway service access point adaptations for WirelessHART® 770
Q.1 General 770
Q.2 Parameters 771
Q.3 Session 771
Q.4 Lease 771
Q.5 Device list report 772
Q.6 Topology report 772
Q.7 Schedule report 772
Q.8 Device health report 773
Q.9 Neighbor health report 773
Q.10 Network health report 774
Q.11 Time 774
Q.12 Client/server 774
Q.13 Publish/subscribe 775
Q.14 Bulk transfer 776
Q.15 Alert 776
Q.16 Gateway configuration 777
Q.17 Device configuration 777
Annex R (INFORMATIVE) Host system interface to standard-compliant devices via a gateway 778
R.1 Background 778
R.2 Device application data integration with host systems 779
R.3 Host system configuration tool 779
R.4 Field device / distributed control systems integration 781
R.5 Gateway 781
R.6 Asset management application support 782
Annex S (INFORMATIVE) Symmetric Key Operation Test Vectors 783
S.1 DPDU samples 783
S.2 TPDU samples 784

Annex T (INFORMATIVE) Data link header and network header for join requests 786
T.1 Overview 786
T.2 MAC header (MHR).....786
T.3 DL header (DHR) 786
T.4 NL header.....786
Bibliography 788

Table 1 – Standard management object types in DMAP 95
Table 2 – Meta_Data_Attribute data structure.....97
Table 3 – Alert types for communication diagnostic category.....98
Table 4 – Alert types for security alert category 98
Table 5 – Alert types for device diagnostic alert category.....98
Table 6 – Alert types for process alert category 99
Table 7 – ARMO attributes 100
Table 8 – ARMO alerts.....103
Table 9 – Alarm_Recovery method 104
Table 10 – DMO attributes 107
Table 11 – DMO alerts 113
Table 12 – System management object types.....116
Table 13 – DSO attributes 118
Table 14 – Address_Translation_Row data structure 118
Table 15 – Read_Address_Row method.....120
Table 16 – Input argument usage 121
Table 17 – Output argument usage 121
Table 18 – Attributes of SMO in system manager 123
Table 19 – Proxy_System_Manager_Join method.....124
Table 20 – Proxy_System_Manager_Contract method 125
Table 21 – Effect of Different Join Commands on Attribute Sets 127
Table 22 – Attributes of DMSO in system manager 127
Table 23 – System_Manager_Join method 128
Table 24 – System_Manager_Contract method.....129
Table 25 – Attributes of STSO in system manager 133
Table 26 – Attributes of SCO in system manager.....136
Table 27 – SCO method for contract establishment, modification, or renewal 138
Table 28 – Input argument usage 143
Table 29 – Output argument usage 144
Table 30 – Contract_Data data structure 147
Table 31 – New_Device_Contract_Response data structure.....150
Table 32 – SCO method for contract termination, deactivation and reactivation.....156
Table 33 – DMO method to terminate contract.....156
Table 34 – DMO method to modify contract 158
Table 35 – Security levels 165

Table 36 – Structure of the security control field 166
Table 37 – Sec.DpduPrep.Request elements 170
Table 38 – Sec.DpduPrep.Response elements 171
Table 39 – Sec.DLAckCheck.Request elements 172
Table 40 – Sec. DLAckCheck.Response elements 172
Table 41 – Sec.DpduCheck.Request elements 173
Table 42 – Sec.DpduCheck.Response elements 174
Table 43 – Sec.DLAckPrep.Request elements 174
Table 44 – Sec.DLAckPrep.Response elements 175
Table 45 – Structure of the WISN DPDU nonce 176
Table 46 – Structure of the 32-bit truncated TAI time 176
Table 47 – TSS “pseudo-header” structure 181
Table 48 – Sec.TpduOutCheck.Request elements 184
Table 49 – Sec.TpduOutCheck.Response elements 184
Table 50 – Sec.TpduSecure.Request elements 185
Table 51 – Sec. TpduSecure.Response elements 186
Table 52 – Sec.TpduInCheck.Request elements 187
Table 53 – Sec.TpduInCheck.Response elements 187
Table 54 – Sec.TpduVerify.Request elements 188
Table 55 – Sec.TpduVerify.Response elements 189
Table 56 – Structure of TL security header 189
Table 57 – Structure of the TPDU nonce 190
Table 58 – Structure of 32-bit nominal TAI time 190
Table 59 – Proxy_Security_Sym_Join method 201
Table 60 – Security_Sym_Join method 201
Table 61 – Security_Confirm method 202
Table 62 – Security_Sym_Join_Request data structure 202
Table 63 – Security_Sym_Join_Response data structure 203
Table 64 – Structure of compressed Security level field 204
Table 65 – Master key security level 205
Table 66 – Structure of KeyHardLifeSpan field 205
Table 67 – Security_Sym_Confirm data structure 206
Table 68 – Implicit certificate format 207
Table 69 – Usage_Serial structure 208
Table 70 – Proxy_Security_Pub_Join method 213
Table 71 – Security_Pub_Join method 213
Table 72 – Proxy_Security_Pub_Confirm method 214
Table 73 – Security_Pub_Confirm method 214
Table 74 – Network_Information_Confirmation method 215
Table 75 – Format of asymmetric join request internal structure 216
Table 76 – Format of the protocol control field 216
Table 77 – Format of asymmetric join response internal structure 217
Table 78 – Format of first join confirmation internal structure 218

Table 79 – Format of join confirmation response internal structure 219
Table 80 – Join process and device lifetime state machine 221
Table 81 – Security_New_Session method 226
Table 82 – Security_New_Session_Request data structure 227
Table 83 – Security_New_Session_Response data structure 228
Table 84 – New_Key method 230
Table 85 – Security_Key_and_Policies data structure 232
Table 86 – Security_Key_Update_Status data structure 234
Table 87 – Session and DL key state transition 235
Table 88 – Attributes of PSMO in the system manager 236
Table 89 – Structure of Policy field 238
Table 90 – Key types 239
Table 91 – Key usage 239
Table 92 – Granularity 239
Table 93 – Device security management object attributes 244
Table 94 – KeyDescriptor (INFORMATIVE) 246
Table 95 – TL KeyLookupData OctetString fields 247
Table 96 – Delete key method 248
Table 97 – Key_Policy_Update method 249
Table 98 – DSMO Alerts 250
Table 99 – Timing requirements 251
Table 100 – Graph table on ND20 257
Table 101 – Graph table on ND21 257
Table 102 – Approximating nominal timing with 32 kHz clock (INFORMATIVE) 284
Table 103 – DL_Config_Info structure 308
Table 104 – DD-DATA.request parameters 315
Table 105 – DD-DATA.confirm parameters 316
Table 106 – Value set for status parameter 316
Table 107 – DD-DATA.indication parameters 317
Table 108 – ExtDLUint, one-octet variant 319
Table 109 – ExtDLUint, two-octet variant 319
Table 110 – Data frame MHR 320
Table 111 – DHDR frame control octet 321
Table 112 – Data frame DMXHR 321
Table 113 – DROUT structure, compressed variant 322
Table 114 – DROUT structure, uncompressed variant 323
Table 115 – DADDR structure 324
Table 116 – Acknowledgement frame MHR 325
Table 117 – Acknowledgement frame DHR 326
Table 118 – DHR ACK/NACK frame control 326
Table 119 – Advertisement DAUX structure 328
Table 120 – Advertisement selections elements 328
Table 121 – Advertisement selections 329

Table 122 – Advertisement time synchronization elements 329
Table 123 – Advertisement time synchronization structure 329
Table 124 – Join superframe information subfields 330
Table 125 – Join superframe information structure 330
Table 126 – Superframe derived from advertisement 331
Table 127 – Join information elements 331
Table 128 – Join information structure 332
Table 129 – Defaults for links created from advertisements 333
Table 130 – dlmo.Neighbor entry created from advertisements 334
Table 131 – dlmo.Graph entry created from advertisements 334
Table 132 – dlmo.Route entry created from advertisements 334
Table 133 – Solicitation header subfields 336
Table 134 – Solicitation header structure 336
Table 135 – Solicitation DAUX fields 336
Table 136 – Solicitation DAUX structure 336
Table 137 – Activate link DAUX fields 338
Table 138 – Activate link DAUX structure 338
Table 139 – Reporting received signal quality DAUX fields 338
Table 140 – Report received signal quality DAUX structure 338
Table 141 – DLMO attributes 340
Table 142 – Subnet filter octets 347
Table 143 – dlmo.TaiAdjust OctetString fields 348
Table 144 – dlmo.TaiAdjust OctetString structure 348
Table 145 – dlmo.EnergyDesign OctetString fields 348
Table 146 – dlmo.EnergyDesign OctetString structure 348
Table 147 – dlmo.DeviceCapability OctetString fields 349
Table 148 – dlmo.DeviceCapability OctetString structure 349
Table 149 – dlmo.DiscoveryAlert fields 351
Table 150 – dlmo.DiscoveryAlert structure 351
Table 151 – dlmo.Candidates OctetString fields 352
Table 152 – dlmo.Candidates structure 352
Table 153 – dlmo.SmoothFactors OctetString fields 353
Table 154 – dlmo.SmoothFactors structure 353
Table 155 – dlmo.QueuePriority fields 354
Table 156 – dlmo.QueuePriority structure 354
Table 157 – dlmo.ChannelDiag fields 355
Table 158 – dlmo.ChannelDiag structure 355
Table 159 – dlmo.Ch fields 357
Table 160 – dlmo.Ch structure 357
Table 161 – Receive template fields 360
Table 162 – Receive template structure 360
Table 163 – Transmit template fields 361
Table 164 – Transmit template structure 361

Table 165 – Default receive template 362
Table 166 – Default transmit template 362
Table 167 – Default receive template for scanning 362
Table 168 – dlmo.Neighbor fields 364
Table 169 – dlmo.Neighbor structure 364
Table 170 – ExtendGraph fields 366
Table 171 – ExtGraph structure 366
Table 172 – dlmo.NeighborDiagReset fields 366
Table 173 – dlmo.NeighborDiagReset structure 366
Table 174 – dlmo.Superframe fields 367
Table 175 – dlmo.Superframe structure 368
Table 176 –dlmo.SuperframeIdle fields 371
Table 177 – dlmo.SuperframeIdle structure 371
Table 178 – dlmo.Graph 372
Table 179 – dlmo.Graph structure 372
Table 180 – dlmo.Link fields 373
Table 181 – dlmo.Link structure 374
Table 182 – dlmo.Link[].Type structure 375
Table 183 – Allowed dlmo.Link[].Type combinations 376
Table 184 – Values for dlmo.Link[].Schedule 377
Table 185 – dlmo.Route fields 377
Table 186 – dlmo.Route structure 378
Table 187 – dlmo.NeighborDiag fields 379
Table 188 – Diagnostic Summary OctetString fields 379
Table 189 – Diagnostic Summary OctetString structure 380
Table 190 – Diagnostic ClockDetail OctetString fields 380
Table 191 – Diagnostic ClockDetail OctetString structure 381
Table 192 – Read_Row method 381
Table 193 – Write_Row method 382
Table 194 – Write_Row_Now method 382
Table 195 – dlmo.AlertPolicy fields 383
Table 196 – dlmo.AlertPolicy OctetString structure 383
Table 197 – DL_Connectivity alert 384
Table 198 – DL_Connectivity alert OctetString 384
Table 199 – NeighborDiscovery alert 385
Table 200 – Link local address structure 387
Table 201 – Address translation table (ATT) 387
Table 202 – Example of a routing table 393
Table 203 – N-DATA.request elements 404
Table 204 – N-DATA.confirm elements 405
Table 205 – N-DATA.indication elements 406
Table 206 – NLMO attributes 407
Table 207 – Contract table structure 410

Table 208 – Route table elements 411
Table 209 – Address translation table structure 411
Table 210 – NLMO structured MIB manipulation methods 412
Table 211 – Alert to indicate dropped PDU/PDU error 413
Table 212 – Common header patterns 414
Table 213 – Basic network layer header format 415
Table 214 – Contract-enabled network layer header format 416
Table 215 – 6LoWPAN_IPHC encoding format 417
Table 216 – IPv6 network layer header format 418
Table 217 – Full network layer header in the DL 419
Table 218 – Network layer header format for fragmented NPDUs 419
Table 219 – First fragment header format 419
Table 220 – Second and subsequent fragment header format 420
Table 221 – UDP header encoding 423
Table 222 – UDP LowPAN_NHC encoding 427
Table 223 – Optimal UDP header encoding 427
Table 224 – UDP header encoding with checksum 428
Table 225 – T-DATA.request elements 429
Table 226 – T-DATA.confirm elements 430
Table 227 – T-DATA.confirm status codes 430
Table 228 – T-DATA.indication elements 431
Table 229 – TLMO attributes 432
Table 230 – Transport layer management object methods – Reset 434
Table 231 – Transport layer management object methods – Halt 434
Table 232 – Transport layer management object methods – PortRangeInfo 435
Table 233 – Transport layer management object methods – GetPortInfo 435
Table 234 – Transport layer management object methods – GetNextPortInfo 436
Table 235 – Transport layer management object alert types – Illegal use of port 436
Table 236 – Transport layer management object alert types – TPDU received on unregistered port 437
Table 237 – Transport layer management object alert types – TPDU does not match security policies 437
Table 238 – State table for alarm transitions 445
Table 239 – State table for event transitions 446
Table 240 – UAP management object attributes 462
Table 241 – State table for UAP management object 463
Table 242 – UAP management object methods 464
Table 243 – Alert receiving object attributes 465
Table 244 – State table for handling an AlertReport reception 465
Table 245 – AlertReceiving object methods 466
Table 246 – UploadDownload object attributes 468
Table 247 – UploadDownload object methods 471
Table 248 – UploadDownload object StartDownload method 472
Table 249 – UploadDownload object DownloadData method 473

Table 250 – UploadDownload object EndDownload method 475
Table 251 – UploadDownload object StartUpload method 476
Table 252 – UploadDownload object UploadData method 477
Table 253 – UploadDownload object EndUpload method 478
Table 254 – Download state table for unicast operation mode 479
Table 255 – Upload state table for unicast operation mode 481
Table 256 – Concentrator object attributes 484
Table 257 – Concentrator object methods 485
Table 258 – Dispersion object attributes 486
Table 259 – Dispersion object methods 487
Table 260 – Tunnel object attributes 488
Table 261 – Tunnel object methods 490
Table 262 – Interface object attributes 491
Table 263 – Interface object methods 491
Table 264 – Data type: ObjectAttributeIndexAndSize 492
Table 265 – Data type: Communication association endpoint 493
Table 266 – Data type: Communication contract data 494
Table 267 – Data type: Alert communication endpoint 495
Table 268 – Data type: Tunnel endpoint 495
Table 269 – Data type: Alert report descriptor 496
Table 270 – Data type: Process control alarm report descriptor for analog with single reference condition 496
Table 271 – Data type: ObjectIDandType 497
Table 272 – Data type: Unscheduled correspondent 497
Table 273 – AL services 498
Table 274 – Publish service 501
Table 275 – Read service 508
Table 276 – Write service 512
Table 277 – Execute service 515
Table 278 – AlertReport service 521
Table 279 – AlertAcknowledge service 524
Table 280 – Tunnel service 527
Table 281 – Application flow characteristics 530
Table 282 – Application service primitive to transport service primitive mapping 531
Table 283 – ASLMO attributes 533
Table 284 – Application sub-layer management object methods 534
Table 285 –Reset method 535
Table 286 – ASLMO alerts 536
Table 287 – Analog input object attributes 539
Table 288 – Analog input object methods 540
Table 289 – Analog input alerts 541
Table 290 – Analog output attributes 543
Table 291 – Analog output object methods 544

Table 292 – Analog output alerts 545
Table 293 – Binary input object attributes 547
Table 294 – Binary input object methods 548
Table 295 – Binary input alerts 548
Table 296 – Binary output attributes 549
Table 297 – Binary output object methods 550
Table 298 – Binary output alerts 550
Table 299 – Status octet 551
Table 300 – Data type: Process value and status for analog value 552
Table 301 – Data type: Process value and status for binary value 552
Table 302 – Data type: Process control mode 553
Table 303 – Data type: Process control mode bitstring 553
Table 304 – Data type: Process control scaling 554
Table 305 – Process control standard objects 554
Table 306 – Services 554
Table 307 – Application messaging format 555
Table 308 – Concatenated APDUs in a single TSDU 555
Table 309 – Object addressing 556
Table 310 – Four-bit addressing mode APDU header construction 556
Table 311 – Eight-bit addressing mode APDU header construction 556
Table 312 – Sixteen-bit addressing mode APDU header construction 557
Table 313 – Inferred addressing use case example 557
Table 314 – Inferred addressing mode APDU header construction 557
Table 315 – Six-bit attribute identifier, not indexed 558
Table 316 – Six-bit attribute identifier, singly indexed, with seven-bit index 558
Table 317 – Six-bit attribute identifier, singly indexed, with fifteen-bit index 558
Table 318 – Six-bit attribute identifier, doubly indexed, with two seven-bit indices 559
Table 319 – Six-bit attribute identifier, doubly indexed, with two fifteen-bit indices 559
Table 320 – Six-bit attribute identifier, doubly indexed, with first index seven-bits long and second index fifteen bits long 559
Table 321 – Six-bit attribute bit attribute identifier, doubly indexed, with first index fifteen bits long and second index seven bits long 559
Table 322 – Twelve-bit attribute identifier, not indexed 559
Table 323 – Twelve-bit attribute identifier, singly indexed with seven-bit index 560
Table 324 – Twelve-bit attribute identifier, singly indexed with fifteen bit identifier 560
Table 325 – Twelve-bit attribute identifier, doubly indexed with two seven bit indices 560
Table 326 – Twelve-bit attribute identifier, doubly indexed with two fifteen bit indices 560
Table 327 – Twelve-bit attribute identifier, doubly indexed with first index seven-bits long and second index fifteen-bits long 560
Table 328 – Twelve-bit attribute identifier, doubly indexed with the first index fifteen bits long and the second index seven bits long 561
Table 329 – Twelve-bit attribute identifier, reserved form 561
Table 330 – Coding rules for read service request 561
Table 331 – Coding rules for read service response with seven bit length field 561

Table 332 – Coding rules for read service response with fifteen-bit length field 562
Table 333 – Coding rules for write service request with seven bit length field 562
Table 334 – Coding rules for write service request with fifteen-bit length field 562
Table 335 – Coding rules for write service response 562
Table 336 – Coding rules for execute service request with seven-bit length field 563
Table 337 – Coding rules for execute service request with fifteen-bit length field 563
Table 338 – Coding rules for execute service response with 7-bit length field 563
Table 339 – Coding rules for execute service response with 15-bit length field 563
Table 340 – Coding rules for tunnel service request with seven-bit length field 564
Table 341 – Coding rules for tunnel service request with fifteen-bit length field 564
Table 342 – Coding rules for tunnel service response with seven-bit length field 564
Table 343 – Coding rules for tunnel service response with fifteen-bit length field 564
Table 344 – Coding rules for AlertReport service with seven bit length field 565
Table 345 – Coding rules for AlertReport service with fifteen-bit length field 565
Table 346 – Coding rules for AlertAcknowledge service 565
Table 347 – Coding rules for publish service for a native sequence of values 565
Table 348 – Coding rules for publish service – non-native (for tunnel support) 566
Table 349 – Coding rules for concatenate service 566
Table 350 – General coding rule for size-invariant application data 566
Table 351 – Coding rules for application data of varying size 566
Table 352 – Coding rules for Boolean data – true 567
Table 353 – Coding rules for Boolean data – false 567
Table 354 – Coding rules for Unsigned8 568
Table 355 – Coding rules for Unsigned16 568
Table 356 – Coding rules for Unsigned32 568
Table 357 – Coding rules for Unsigned64 569
Table 358 – Coding rules for Unsigned128 569
Table 359 – Coding rules for Float 570
Table 360 – Coding rules for double-precision float 570
Table 361 – Coding rules for VisibleString 571
Table 362 – Coding rules for OctetString 571
Table 363 – Coding rules for Bitstring 571
Table 364 – Example of coding for Bitstring of size 8 571
Table 365 – Coding rules for TAITimeDifference 572
Table 366 – Coding rules for TAINetworkTimeValue 572
Table 367 – Coding rules for TAITimeRounded 573
Table 368 – Coding example: Read request for a non-indexed attribute 587
Table 369 – Coding example: Read response (corresponding to request contained in the preceding table) 588
Table 370 – Coding example: Tunnel service request 588
Table 371 – Summary of gateway high side interface services 594
Table 372 – Primitive G_Session parameter usage 603
Table 373 – GS_Status for G_Session confirm 604

Table 374 – Primitive G_Lease parameter usage 604
Table 375 – GS_Lease_Type for G_Lease request 605
Table 376 – GS_Status for G_Lease confirm 606
Table 377 – Primitive G_Device_List_Report parameter usage 607
Table 378 – GS_Status for G_Device_List_Report confirm 608
Table 379 – Primitive G_Topology_Report parameter usage 608
Table 380 – GS_Status for G_Topology_Report confirm 609
Table 381 – Primitive G_Schedule_Report parameter usage 609
Table 382 – GS_Status for G_Schedule_Report confirm 611
Table 383 – Primitive G_Device_Health_Report parameter usage 611
Table 384 – GS_Status for G_Device_Health_Report confirm 612
Table 385 – Primitive G_Neighbor_Health_Report parameter usage 612
Table 386 – GS_Status for G_Device_Health_Report confirm 613
Table 387 – Primitive G_Network_Health_Report parameter usage 614
Table 388 – GS_Status for G_Network_Health_Report confirm 615
Table 389 – Primitive G_Time parameter usage 616
Table 390 – GS_Status for G_Time confirm 616
Table 391 – Primitive G_Client_Server parameter usage 617
Table 392 – GS_Status for G_Client_Server confirm 618
Table 393 – Primitive G_Publish parameter usage 619
Table 394 – GS_Status for G_Publish confirm 620
Table 395 – Primitive G_Subscribe parameter usage 620
Table 396 – GS_Status for G_Subscribe confirm 621
Table 397 – Primitive G_Publish_Timer parameter usage 621
Table 398 – Primitive G_Subscribe_Timer parameter usage 621
Table 399 – Primitive G_Publish_Watchdog parameter usage 622
Table 400 – Primitive G_Bulk_Open parameter usage 623
Table 401 – GS_Status for G_Bulk_Open confirm 623
Table 402 – Primitive G_Bulk_Transfer parameter usage 624
Table 403 – GS_Status for G_Bulk_Transfer confirm 624
Table 404 – Primitive G_Bulk_Close parameter usage 624
Table 405 – GS_Status for G_Bulk_Close confirm 625
Table 406 – Primitive G_Alert_Subscription parameter usage 625
Table 407 – GS_Status for G_Alert_Subscription confirm 626
Table 408 – Primitive G_Alert_Notification parameter usage 627
Table 409 – Primitive G_Read_Gateway_Configuration parameter usage 628
Table 410 – GS_Attribute_Identifier values 628
Table 411 – GS_Status for G_Read_Gateway_Configuration confirm 629
Table 412 – Primitive G_Write_Gateway_Configuration parameter usage 629
Table 413 – GS_Attribute_Identifier values 629
Table 414 – GS_Status for G_Write_Gateway_Configuration confirm 630
Table 415 – Primitive G_Write_Device_Configuration parameter usage 630
Table 416 – GS_Status for G_Write_Device_Configuration confirm 631

Table 417 – Primitive G_Read_Device_Configuration parameter usage 631
Table 418 – GS_Status for G_Read_Device_Configuration confirm 632
Table 419 – UAP management object extended attributes 650
Table 420 – Factory default settings 658
Table 421 – Device provisioning object 664
Table 422 – Reset_To_Default method 668
Table 423 – Write symmetric join key method 668
Table 424 – Device provisioning service object 670
Table 425 – DPSOWhiteListTbl data structure 674
Table 426 – Array manipulation table 675
Table 427 – DPSO alert to indicate join by a device not on the WhiteList 676
Table 428 – DPSO alert to indicate inadequate device join capability 676
Table 429 – Field media type 682
Table 430 – Protocol layer support 683
Table 431 – Device PICS 683
Table 432 – PICS for device implementing I/O role 683
Table 433 – PICS for device implementing router role 684
Table 434 – PICS for backbone router 684
Table 435 – PICS for gateway 684
Table 436 – PICS for system manager 684
Table 437 – PICS for provisioning device 684
Table 438 – PICS for security manager 685
Table 439 – PICS for device implementing system time source role 685
Table 440 – System PICS 685
Table 441 – Device PICS 686
Table 442 – Router and backbone router PICS 686
Table 443 – PICS for system time source 687
Table 444 – PICS for system manager 687
Table 445 – PICS for provisioning role 688
Table 446 – Device PICS 688
Table 447 – PICS for provisioning role 689
Table 448 – PICS for security manager 689
Table 449 – PhL roles 690
Table 450 – PhL frequency of operation 690
Table 451 – PhL functions 690
Table 452 – PhL packet 691
Table 453 – DL roles 691
Table 454 – DL PICS for device implementing I/O role 691
Table 455 – DL PICS for device implementing router role 691
Table 456 – DL PICS for device implementing backbone router role 692
Table 457 – PICS for devices implementing I/O role 692
Table 458 – PICS for device implementing router role 693
Table 459 – PICS for devices implementing backbone router role 693

Table 460 – PICS for device implementing I/O role 694
Table 461 – PICS for routing device 694
Table 462 – PICS for backbone router 694
Table 463 – AL implementation option 695
Table 464 – PICS part 2: Optional industry-independent objects 695
Table 465 – PICS part 2: Supported standard services for I/O device role 696
Table 466 – PICS part 2: Supported standard services for system manager role 697
Table 467 – PICS part 2: Supported standard services for gateway role when supporting native access 698
Table 468 – PICS part 2: Supported standard services for gateway role when supporting interoperable tunneling and for adapters 699
Table 469 – PICS part 2: Supported standard services for routing device role 700
Table 470 – PICS part 2: Supported standard services for backbone router role 701
Table 471 – PICS part 2: Supported standard services for provisioning role 702
Table 472 – PICS part 2: Supported standard services for system time source role 702
Table 473 – Process control conformance: Supported objects 702
Table 474 – Process control conformance: Supported alerts 703
Table 475 – PICS: Gateway 704
Table 476 – PICS: I/O devices, routing devices, gateways, and backbone routers 706
Table 477 – PICS: Provisioning devices 706
Table 478 – Protocol layer device roles 708
Table 479 – Over-the-air upgrades 708
Table 480 – Session support profiles 709
Table 481 – Baseline profiles 709
Table 482 – PhL roles 710
Table 483 – DL required for listed roles 710
Table 484 – Role profiles: General DLMO attributes 711
Table 485 – Role profiles: dlmo.Device_Capability 712
Table 486 – Role profiles: dlmo.Ch (channel hopping) 713
Table 487 – Role profiles: dlmo.TsTemplate 713
Table 488 – Role profiles: dlmo.Neighbor 713
Table 489 – Role profiles: dlmo. NeighborDiag 714
Table 490 – Role profiles: dlmo.Superframe 714
Table 491 – Role profiles: dlmo.Graph 714
Table 492 – Role profiles: dlmo.Link 715
Table 493 – Role profiles: dlmo.Route 715
Table 494 – Role profiles: dlmo.Queue_Priority 715
Table 495 – Routing table size 715
Table 496 – Address table size 716
Table 497 – Port support size 716
Table 498 – APs 716
Table 499 – Role profile: Gateway 716
Table 500 – Role profile: Gateway native access 717
Table 501 – Role profile: Gateway interoperable tunnel mechanism 717

Table 502 – Role profiles: I/O, routers, gateways, and backbone routers 717
Table 503 – Usage classes 718
Table 504 – System management configuration defaults 723
Table 505 – Security configuration defaults 724
Table 506 – DL configuration defaults 725
Table 507 – Network configuration defaults 726
Table 508 – Transport configuration defaults 726
Table 509 – Application configuration defaults 727
Table 510 – Gateway configuration defaults 728
Table 511 – Provisioning configuration defaults 729
Table 512 – Table of standard object types 743
Table 513 – Template for standard object attributes 743
Table 514 – Template for standard object methods 744
Table 515 – Template for standard object alert reporting 745
Table 516 – Template for data structures 746
Table 517 – Scheduled_Write method template 747
Table 518 – Read_Row method template 748
Table 519 – Write_Row method template 748
Table 520 – Reset_Row method template 749
Table 521 – Delete_Row method template 750
Table 522 – Standard object types 753
Table 523 – Standard object instances 755
Table 524 – Standard data types 758
Table 525 – Protocol identification values 759
Table 526 – Sample MHR for join request 786
Table 527 – Sample DHR for join request 786
Table 528 – Network header for join messages 787

Figure 1 – Standard-compliant network 62
Figure 2 – Single protocol data unit 63
Figure 3 – Full protocol data unit 63
Figure 4 – Physical devices versus roles 70
Figure 5 – Notional representation of device phases 73
Figure 6 – Simple star topology 75
Figure 7 – Simple hub-and-spoke topology 76
Figure 8 – Mesh topology 77
Figure 9 – Simple star-mesh topology 77
Figure 10 – Network and DL subnet overlap 78
Figure 11 – Network and DL subnet differ 79
Figure 12 – Network with multiple gateways 80
Figure 13 – Basic network with backup gateway 81

Figure 14 – Network with backbone 82
Figure 15 – Network with backbone – device roles....83
Figure 16 – Reference model 84
Figure 17 – Basic data flow 85
Figure 18 – Data flow between I/O devices....86
Figure 19 – Data flow with legacy I/O device 87
Figure 20 – Data flow with backbone....87
Figure 21 – Data flow between I/O devices via backbone 88
Figure 22 – Data flow to standard-aware control system 89
Figure 23 – Management architecture 91
Figure 24 – DMAP 94
Figure 25 – Example of management SAP flow through standard protocol suite 96
Figure 26 – System manager architecture concept 115
Figure 27 – UAP-system manager interaction during contract establishment 134
Figure 28 – Contract-related interaction between DMO and SCO 136
Figure 29 – Contract source, destination, and intermediate devices....145
Figure 30 – Contract establishment example 153
Figure 31 – Contract ID usage in source 154
Figure 32 – Contract termination....157
Figure 33 – Contract modification with immediate effect....159
Figure 34 – Examples of DPDU and TPDU scope 161
Figure 35 – Keys and associated lifetimes....163
Figure 36 – Key lifetimes....164
Figure 37 – DPDU structure 167
Figure 38 – Outgoing messages – DL and security 168
Figure 39 – Incoming messages- DL and security....169
Figure 40 – TPDU structure and protected coverage....180
Figure 41 – TMIC parameters 180
Figure 42 – Transport layer and security sub-layer interaction, outgoing TPDU 182
Figure 43 – Transport layer and security sub-layer interaction, incoming TPDU....183
Figure 44 – Example: Overview of the symmetric key join process 198
Figure 45 – Example: Overview of the symmetric key join process of backbone device....199
Figure 46 – Asymmetric key-authenticated key agreement scheme 208
Figure 47 – Example: Overview of the asymmetric key join process for a device with a data link layer 211
Figure 48 – Example: Overview of the asymmetric key join process of a backbone device 212
Figure 49 – Device state transitions for join process and device lifetime 221
Figure 50 – High-level example of session establishment....222
Figure 51 – Key update protocol overview....230
Figure 52 – Device session establishment and key update state transition....236
Figure 53 – DL protocol suite and PPDU/DPDU structure....254
Figure 54 – Graph routing example....257
Figure 55 – Inbound and outbound graphs 259

Figure 56 – Slotted hopping 263
Figure 57 – Slow hopping 263
Figure 58 – Hybrid operation 264
Figure 59 – Radio spectrum usage 264
Figure 60 – Default hopping pattern 1 266
Figure 61 – Two groups of devices with different hopping pattern offsets 267
Figure 62 – Interleaved hopping pattern 1 with 16 different hopping pattern offsets 268
Figure 63 – Slotted hopping 269
Figure 64 – Slow hopping 269
Figure 65 – Hybrid mode with slotted and slow hopping 270
Figure 66 – Combining slotted hopping and slow hopping 270
Figure 67 – Example of a three-timeslot superframe 271
Figure 68 – Superframes and links 271
Figure 69 – Multiple superframes, with timeslots aligned 272
Figure 70 – Slotted hopping 275
Figure 71 – Slow hopping 276
Figure 72 – Components of a slow hop 276
Figure 73 – Avoiding collisions among routers 277
Figure 74 – Hybrid configuration 278
Figure 75 – Timeslot allocation and the message queue 280
Figure 76 – 250 ms alignment intervals 283
Figure 77 – Timeslot durations and timing 283
Figure 78 – Clock source acknowledges receipt of DPDU 288
Figure 79 – Transaction timing attributes 290
Figure 80 – Dedicated and shared transaction timeslots 291
Figure 81 – Unicast transaction 292
Figure 82 – PDU wait time (PWT) 294
Figure 83 – Duocast support in the standard 295
Figure 84 – Duocast transaction 296
Figure 85 – Shared timeslots with CSMA-CA 297
Figure 86 – Transaction during slow-hopping periods 298
Figure 87 – DL management SAP flow through standard protocol suite 300
Figure 88 – PPDU and DPDU structure 317
Figure 89 – Typical acknowledgement frame layout 324
Figure 90 – Relationship among DLMO indexed attributes 356
Figure 91 – Address translation process 389
Figure 92 – Fragmentation process 390
Figure 93 – Reassembly process 392
Figure 94 – Processing of a NSDU received from the transport layer 394
Figure 95 – Processing of an incoming NPDU 395
Figure 96 – Processing of a NPDU received from the backbone 396
Figure 97 – Delivery of an incoming NPDU at its final destination 397
Figure 98 – Routing from a field device to a gateway on field – no backbone routing 397

Figure 99 – Protocol suite diagram for routing from a field device to a gateway on field – no backbone routing 398
Figure 100 – Routing a PDU from a field device to a gateway via a backbone router 399
Figure 101 – Protocol suite diagram for routing a PDU from a field device to a gateway via a backbone router 399
Figure 102 – Routing from a field device on one subnet to another field device on a different subnet 401
Figure 103 – Protocol suite diagram for routing from an I/O device on one subnet to another I/O device on a different subnet 402
Figure 104 – Routing over an Ethernet backbone network 403
Figure 105 – Routing over a fieldbus backbone network 403
Figure 106 – Distinguishing between NPDU header formats 414
Figure 107 – Transport layer reference model 421
Figure 108 – UDP “pseudo-header” for IPv6 423
Figure 109 – Transport layer protocol data unit 426
Figure 110 – User application objects in a user application process 440
Figure 111 – Alarm state model 445
Figure 112 – Event model 446
Figure 113 – A successful example of multiple outstanding requests, with response concatenation 451
Figure 114 – An example of multiple outstanding unordered requests, with second write request initially unsuccessful 452
Figure 115 – An example of multiple outstanding ordered requests, with second write request initially unsuccessful 453
Figure 116 – Send window example 1, with current send window smaller than maximum send window 455
Figure 117 – Send window example 2, with current send window the same size as maximum send window, and non-zero usable send window width 455
Figure 118 – Send window example 3, with current send window the same size as maximum send window, and usable send window width of zero (0) 456
Figure 119 – General addressing model 458
Figure 120 – UAP management object state diagram 464
Figure 121 – Alert report reception state diagram 466
Figure 122 – Alert reporting example 466
Figure 123 – Upload/Download object download state diagram 480
Figure 124 – Upload/Download object upload state diagram 482
Figure 125 – Publish sequence of service primitives 500
Figure 126 – Client/server model two-part interactions 504
Figure 127 – Client/server model four-part interactions: Successful delivery 505
Figure 128 – Client/server model four-part interactions: Request delivery failure 505
Figure 129 – Client/server model four-part interactions: Response delivery failure 506
Figure 130 – AlertReport and AlertAcknowledge, delivery success 519
Figure 131 – AlertReport, delivery failure 519
Figure 132 – Alert Report, acknowledgment failure 520
Figure 133 – Concatenated response for multiple outstanding write requests (no message loss) 526

Figure 134 – Management and handling of malformed APDUs received from device X 532
Figure 135 – Gateway scenarios.....591
Figure 136 – Basic gateway model 592
Figure 137 – Sequence of primitives for session service 595
Figure 138 – Sequence of primitives for lease management service 595
Figure 139 – Sequence of primitives for system report services 596
Figure 140 – Sequence of primitives for time service 596
Figure 141 – Sequence of primitives for client/server service initiated from gateway 597
Figure 142 – Sequence of primitives for publish service initiated from gateway 597
Figure 143 – Sequence of primitives for subscribe service initiated from device 598
Figure 144 – Sequence of primitives for publisher timer initiated from gateway 598
Figure 145 – Sequence of primitives for subscriber timers initiated from device 598
Figure 146 – Sequence of primitives for the bulk transfer service 599
Figure 147 – Sequence of primitives for the alert subscription service 599
Figure 148 – Sequence of primitives for the alert notification service 600
Figure 149 – Sequence of primitives for gateway management services 600
Figure 150 – Tunnel object model.....633
Figure 151 – Distributed tunnel endpoints 634
Figure 152 – Multicast, broadcast, and one-to-many messaging.....635
Figure 153 – Tunnel object buffering.....636
Figure 154 – Publish/subscribe publisher CoSt flowchart 638
Figure 155 – Publish/subscribe publisher periodic flowchart.....639
Figure 156 – Publish/subscribe subscriber common periodic and CoSt flowchart.....639
Figure 157 – Network address mappings.....640
Figure 158 – Connection_Info usage in protocol translation 641
Figure 159 – Transaction_Info usage in protocol translation.....642
Figure 160 – Interoperable tunneling mechanism overview diagram.....643
Figure 161 – Bulk transfer model 645
Figure 162 – Alert model 646
Figure 163 – Alert cascading 647
Figure 164 – Native P/S and C/S access.....648
Figure 165 – The provisioning network.....655
Figure 166 – State transition diagrams outlining provisioning steps during a device life cycle 657
Figure 167 – State transition diagram showing various paths to joining a secured network 660
Figure 168 – Provisioning objects and interactions 662
Figure 169 – Basic reference model.....720
Figure 170 – Generic protocol translation publish diagram 762
Figure 171 – Generic protocol translation subscribe diagram 763
Figure 172 – Generic protocol translation client/server transmission diagram.....764
Figure 173 – Generic protocol translation client/server reception diagram.....765
Figure 174 – Host integration reference model 778
Figure 175 – Configuration using an electronic device definition.....780

Figure 176 – Configuration using FDT/DTM approach.....780