Index

\textbf{a}

ACK (Acknowledge) marking mechanism 252–253, 260, 261
Adaptive modulation and coding (AMC) 41
Ad-hoc based mobile traffic offloading 6, 7
AMC. See Adaptive modulation and coding
Application aware adaptation 263
Approximate WUA (AWUA) problem 194
Auction-based decentralized algorithm 70–81
EST scheme and PBSs’ actions 72–81
performance evaluation of SBSs’ actions 73–74

\textbf{b}

Base stations (BSs)
of cellular network 3–4
coalitions formation of 23–24
energy supplies 28
green energy powered 3, 26
energy provisioning 26–27
by green power farms 29–30
and grid powered 31–32
resource management 27–28
standalone generator 29
hybrid energy powered macro 4
off-grid 19, 24
on-grid 19, 24
pico/femto 7

power consumption model 26
primary 61–62
renewable energy provisioning for 110–128
secondary 9, 61–62
into sleep mode, enabling 22
small cell 4
switched off 17
traffic demands at 18
Base stations resource management 27
dynamic processes of 27
energy allocation optimization 28
packet scheduling optimization 27–28
Binary energy system sizing (BESS) algorithm 122
BSs. See Base stations
Burke’s theorem 168
Bytemobile Macara platform 270

\textbf{c}

Caching 247–248
Cell edge communications, increasing energy efficiency for 19–22
cooperative beamforming 20, 21
cooperative relaying 20, 21
distributed space-time coding 20–22
joint transmission 20, 21
Cell range expansion (CRE) technique, for traffic load balancing 130
Cellular network. See also Mobile networks base stations of 3–6
energy consumption of 3, 17
energy efficiency of 3–4 (See also Multi-cell cooperation)
Cellular network (Continued)
energy utilization of 21
future research 22–24
layout 15–17
powering with renewable energy 9
Censor rate 36
Chameleon 271
Closed access architecture, green cognitive
small cells 43
Cognitive functionalities in energy
harvesting 47–50
access strategy 49
detection performance 48–49
harvesting strategy for 47–48
power pricing 50
resource allocation 49
sensing scheduling 49
sensing strategy for 48
Cognitive radio (CR) 10–11
CoMP. See Coordinated multi-point
Content adaptation techniques 263
Content delivery, mobile network
optimization via 239–277
application misbehavior 243
cross domain techniques for 247
control plane latency reduction 245–246
first packet delay 242
user plane latency reduction 246–247
integrating mobile networks and CDN
247
mobile data offloading 264
direct data offloading 264–265
MAR 265–266
network aggregation methods 265–266
pTCP 265
super-aggregation 266
through metro scale WiFi 264–265
through opportunistic
communications 264
mobile devices 243–244
multimedia 272–277
network asymmetry 241
network domain techniques for 249
handover optimization techniques
249
network coding 250–251
queue management techniques
249–250
session layer techniques 261–262
TCP optimization 251–261
packet retransmission 240
queue management 241–242
queuing in 240–241
TCP flaws 242
TCP ACK compression 243
TCP slow start 242–243
user mobility 244
web 266–272
Content domain techniques 247
caching 247–248
data compression 249
data redundancy elimination 248
prefetching 248
Content owner selection (COS) problem
205
Control plane protocol 57
Cooperative beamforming 20, 21
Cooperative CR systems 39–42
Cooperative networking 205
Cooperative relaying (CR) 20, 21
Cooperative sensing scheduling (CSS) 36
Coordinated multi-point (CoMP)
transmissions 4, 19
BSs into sleep mode, enabling 22
cell edge communications, energy
efficiency for 19–22
green energy aware 31
COS. See Content owner selection
CR. See Cognitive radio; Cooperative
relaying
Cross domain techniques for content
delivery 262
Index

content adaptation techniques 263
protocol adaptation techniques 263–264
d
Data compression 249
Data redundancy elimination 248
Data Rendezvous protocol 265
D2D. See Device-to-device
Delta encoding 249
Device-to-device (D2D) communications 6, 7
disadvantages 8–9
GCB and 204–205, 211–236
green relay assisted 203–205, 212–221
and proximity services 8–9, 203–236
(See also Specific services)
GCB 221–236
green relay 212–221
wireless multicasting 205–212
SD pairs and 203–205
Distributed space-time coding 20–22
DRA. See Dynamic resource allocation
DSA. See Dynamic spectrum access
Dynamic power consumption 26
BS 142, 189–190
GCB 223–224
LBS 132
MBS 113
PBS 65, 69, 72, 79, 80
relay node’s 213–214
SBS 81, 111
Dynamic resource allocation (DRA) 38–39
Dynamic spectrum access (DSA) network 34
e
EDR. See Energy depleting ratio
EDS. See Energy dependent set
ELLA. See Energy loss and latency aware
Energy allocation optimization 28
Energy aware CR systems 34
Energy consumption, of cellular
network 3
Energy dependent set (EDS) 102–103
Energy depleting ratio (EDR) 96, 101–104, 108
Energy harvesting techniques 44
cognitive functionalities in 47–50
green energy utilization and
optimization 46–47
models 44–45
reception policy 46–47
transmission policy 46
Energy loss and latency aware (ELLA) user
association scheme 193–195
Energy saving greedy (ESG) algorithm 232, 234–235
Energy savings maximization (ESM) problem 72–73
Energy spectrum trading (EST) scheme 61
algorithm 63–70
auction-based 72–81
communications model in 64
energy consumption model in 65
HPCM algorithm 67–70
illustration of 62
PBS and SBSs 63
performance evaluation of 81–87
problem formulation and analysis in 65–67
EPS. See Evolved Packet System
ESM. See Energy savings maximization
EST. See Energy spectrum trading
EUTRAN 245
control plane latency reduction 245–246
user plane latency reduction 246–247
Evolved Packet System (EPS) 11
f
First packet delay 242
FreeNet 50–51
application 51
broadband services in rural areas 52
emergency communications capability
in critical situations 52
network congestion in urban areas,
alleviation of 51–52
communication protocol suite design 57
control plane protocol 57
power plane protocol 57
user plane protocol 57–58
Index

FreeNet (Continued)
dynamic network architecture 53–54
optimization 53–54
grid power consumption versus delay 55–56
grid power consumption versus delay of diversified applications 56
grid power consumption versus loss of diversified applications 57
optimal network resource management 54
renewable energy sharing 55
spectrum sensing and sharing 54–55

Green energy
aware base station sleeping 30–31
aware CoMP 31
aware user association 30
ICE to optimize utilization of 131–138
models 25, 44–45
green power generation 25
harvesting 44–45
mobile network energy consumption 25–26
provisioning 26–27, 91
solar energy 92
system sizing 120–122
utilization and optimization 46–47, 91
challenges on 47
scheme for mobile networks with hybrid energy supplies 91–110
Green energy aware and latency aware (GALA), user association scheme 30
Green energy enabled mobile networks 9–13, 28–32
green and grid powered base stations 31–32
off-grid
powered by green power farms 29–30
powered by standalone green power generator 29
on-grid 30
green energy aware base station sleeping 30–31
green energy aware CoMP 31
green energy aware user association 30
Green energy optimization (GEO) schemes 91
algorithm 99–100
EA 105–106
illustration of 100
MEA 100–102
MEB 102–105
mobile networks with hybrid energy supplies 91–110
algorithm 99–106
performance evaluation 106–110

GALA. See Green energy aware and latency aware
Gateway GPRS support node (GGSN) 240–241
GCB. See Green content brokerage
General user association problem (GUA) problem 152
3rd Generation Partnership Project (3GPP) 11
GEO. See Green energy optimization
GEP. See Green energy provisioning
GGSN. See Gateway GPRS support node
3GPP. See 3rd Generation Partnership Project
GPRSWeb 267–268
Green cognitive small cells 42–43
closed access architecture 43
open access architecture 43
Green communications via cognitive radio
communications 9–11
via optimizing mobile content delivery 11–13
Green content brokerage (GCB) 204–205, 221–224
heuristic traffic offloading algorithm 227–232
computational complexity 232
COS problem 226–227
performance evaluation 232–235
problem formulation and analysis 224–226
Index

problem formulation 95–99
system model 93–95
problem 92
decomposition, rationale of 98–99
MEA 96–97
MEB 97–98
Green energy powered mobile base stations 26
green energy provisioning 26–27
resource management 27–28
Green energy provisioning (GEP) problem 91
Green networking technologies base stations of 3–4 (See also Base stations (BSs))
communications via cognitive radio communications 9–11
via optimizing mobile content delivery 11–13
D2D communications and 8–9
fundamental 3–13
heterogeneous networking and 4–6
mobile traffic offloading and 6–8
multi-cell cooperation in 3–4
powering mobile networks with renewable energy 9
proximity services and 8–9
Green relay assisted (GRA) D2D communications 203–205, 212
advantages 203
communications model 212–213
cooperative communications, illustration of 213
energy model 213–214
green content broker and 204–205
heuristic, assignment algorithm 214–217
optimal relay assignment and 217–221
performance of 217–221
problem formulation 214
traffic model 213
utilization of 203
Green relaying systems 39–42
Green traffic capacity 143
GUA. See General user association problem

h
Handover optimization techniques 249
Harvest-use architecture, of cognitive device 44–45
Heterogeneous CR system 42–43
Heterogeneous networking (HetNet) 4–6, 42, 129
MBSs and 8
powered by hybrid energy sources 139
SCBSs and 8
traffic load balancing in 129–131
user–BS associations in 7–8
Heuristic algorithm 63
Heuristic power consumption minimization (HPCM) algorithm 67–70, 71, 77–81
Hotspots 5
HPCM. See Heuristic power consumption minimization
HTTP streaming 239
Hybrid automatic repeat request (HARQ) efficiency of 250
layer 240
network coded 250
Hybrid spectrum sharing 38

i
ICE. See Intelligent cell breathing
Infrastructure based mobile traffic offloading 6, 7
In-Motion proxy protocol 265
Intelligent cell breathing (ICE) 3–4
algorithm 133–135
performance 135–138
design of 134
to optimize utilization of green energy 131–138
algorithm 133–138
problem formulation 132–133
pseudo code for 134
for traffic load balancing 131–138
Internet of Things (IoT) 6
Internet service provider (ISP) 61
hotspots 61
Inter-web page compression techniques 249
Index

Intra-web page compression techniques 249
IoT. See Internet of Things
ISP. See Internet service provider

j
Joint transmission 20, 21

k
Karush-Kuhn-Tucker (KKT) conditions 68
Kuhn-Munkres algorithm 232

I
LOEP. See Loss of energy probability
LOLP. See Loss of load probability
Loss of energy probability (LOEP) 27
Loss of load probability (LOLP) 27
Lozano’s algorithm 207–211

m
Macro base stations (MBSs) 4, 6
green energy provisioning for 113–116
heterogeneous networking and 8
pico/femto BSs and 7
MAR, mobile data offloading 265–266
MBSs. See Macro base stations
MEA. See Multi-stage energy allocation
MEB. See Multi-BSs energy balancing
MIMO. See Multi-input-multi-output
Mobile data offloading
through metro scale WiFi 264–265
through opportunistic communications 264
Mobile networks 61
advantages of 61
content delivery acceleration solutions in 11–13
content delivery in 239–277
downlink scheduling algorithms 141
energy consumption of 25–26
green energy powered 9–13, 28–32
with hybrid energy supplies, GEO schemes 91–110
decomposition, rationale of 98–99
green energy consumption model 94

n
network scenario 93
network traffic model 94–95
problem formulation 95–99
measurements, for accelerating content delivery
application misbehavior 243
first packet delay 242
mobile devices 243–244
network asymmetry 241
packet retransmission 240
queue management 241–242
queueing in 240–241
TCP flaws 242–243
user mobility 244
mobile communications system evolution
and 11
powering with renewable energy 9
primary users 61–62
quality of experience (QoE) in 11
secondary users 61–62
TCP performance in 250–251
traffic load balancing in 129–131
cell range expansion (CRE) technique for 130
handover procedures for 130
Intelligent Cell brEathing (ICE) for 131–138
problem 130
Mobile traffic offloading 6
ad-hoc based 6, 7
infrastructure based 6, 7
ISP and 61
user–BS associations in heterogeneous mobile networks 7–8
Multi-BSs energy balancing (MEB) algorithm 102–105
problem 92, 97–98
Multicast beamforming 205
Multicast scheduling optimization 276
Multi-cell cooperation 3–4, 15
CoMP transmission 19–22
energy aware 19
future research 22–23
coalition formation 23–24
green energy utilization 24
incentive mechanism 24
network layout 15–17
traffic intensity aware 15–18
optimize switching off strategy 18
traffic demand estimation 17–18
Multi-input-multi-output (MIMO) system 11, 53
Multimedia content delivery acceleration 272
adaptive streaming 273–274
client side mechanisms 274
server side algorithms 275
cooperative delivery 277
multicast scheduling optimization 276
multiple HTTP/TCP connections 276
multiple path aggregation 276
priority-based protection 276
Multi-stage energy allocation (MEA) algorithm 100–102
problem 92, 96–97

n
Nett-Gain 269–270
Network asymmetry 241
Network coding techniques 250
hybrid automatic repeat request efficiency 250
TCP performance in mobile networks 250–251
Network domain techniques handover optimization techniques 249
network coding 250–251
queue management techniques 249–250
session layer techniques 261–262
TCP optimization 251–261
Network layout, of cellular networks 15–17
traffic demand estimation and 17–18
Network utility aware (NUA) traffic load balancing 166
energy–latency trade-off, adaptation of 176
performance of algorithms 177
simulation results 177–187
simulation setup 176–177
procedures 171
user association 171–173, 178
algorithm, properties of 173–176
Non-interfering Prefetching System (NPS) 270
NPS. See Non-interfering Prefetching System
NUA. See Network utility aware

O
O-DSTC. See Opportunistic distributed space-time coding
OFDMA. See Orthogonal frequency-division multiple access
Off-grid base stations 19, 24
Off-grid green mobile networks powered by green power farms 29–30
powered by standalone green power generator 29
Offloading mobile traffic to small cell base stations 6
On-grid base stations 19, 24
On-grid green mobile networks 30
green energy aware base station sleeping 30–31
green energy aware CoMP 31
green energy aware user association 30
Open access architecture, green cognitive small cells 43
Opportunistic distributed space-time coding (O-DSTC) 22
Optimal relay assignment (ORA) algorithm 217–221
Orange 9
Orthogonal frequency-division multiple access (OFDMA) 11

P
Packet retransmission 240
Packet scheduling optimization 27–28
Partially observable Markov decision process (POMDP) framework 37
PCM. See Power consumption minimization
PDUs. See Protocol data units
Poisson process 167, 168
Index

POMDP. See Partially observable Markov decision process

Power consumption minimization (PCM)
- problem 63–68
- algorithm 76–77

Power grid dynamics 27

Power plane protocol 57

Prefetching, content domain techniques 248

Primary base stations (PBSs) 61–62
- auction-based decentralized algorithm and 70–81
  - in EST scheme 63–65
  - power consumption 65, 72

Primary users (PUs), of mobile networks 61–62

Protocol adaptation techniques 263–264

Protocol data units (PDUs) 240

Provisioning cost aware (PCA) traffic load balancing 118–120

Proxy based adaptation 263

pTCP, mobile data offloading 265, 266

pTHINC 271

RED. See Random early detection

Relay enhanced cooperative spectrum sensing 40–41

Renewable energy, for mobile networks 9

Renewable energy provisioning for base stations 110–111
- energy model in 113–114
- green power system 111–112
- performance evaluation 124–128
- problem formulation in 114–116
- problem solution in 116–123
  - computational complexity 122–123
  - green energy system sizing 120–122
  - PCA traffic load balancing scheme 118–120
  - problem decomposition 116–117
  - traffic model in 112–113

RLC (Radio Link Control) layer ARQ 240

RRC. See Radio resource control

RSSI. See Received-signal-strength-indication

QoE. See Quality of experience

QoS. See Quality of service

Quality of experience (QoE), in mobile networks 11

Quality of service (QoS) 62
- data services with 61

Queue management 241–242, 249–250
- in mobile core networks 240–241

Radio access network controller (RANC) 138, 144–145
- in balancing traffic loads 154
- vGALA scheme and 154

Radio frequency energy harvesting 45

Radio resource control (RRC) states 242

RANC. See Radio access network controller

Random early detection (RED) 241

Received-signal-strength-indication (RSSI) 129

S

SBS. See Secondary base stations

SCBS. See Small cell base stations

SCNs. See Small cell networks

Secondary base stations (SBSs) 9, 61–62
- auction-based decentralized algorithm and 70–81
  - in EST scheme 63–65
  - rate adaptation algorithm 74

Secondary users (SUs), of mobile networks 61–62

Sequential channel scheduling 36–37

Serving content selection (SCS) problem 205

Serving GPRS support node (SGSN) 240–241

Session layer techniques 261–262
- concurrent TCP connections, reducing number of 262
- DNS lookups, reducing number of 262
- TCP idle time, reduction of 262

SGSN. See Serving GPRS support node

Shannon–Hartley theorem 72, 140

Signal interference noise ratios (SINRs) 29, 129, 140
Silo 271–272
Simplified PCM (SPCM) problem 67
SINRs. See Signal interference noise ratios
Sleeping rate 36
Small cell base stations (SCBSs) 4, 53, 165
deployment strategies 4–6
heterogeneous networking and 8
offloading mobile traffic to 6
Small cell networks (SCNs) 130, 131
traffic load balancing in backhaul
constrained 165–185
Smart grid enabled mobile networks
188–189
BS operation and 188–189
CO2 emissions and 188
power distribution and 188–189
traffic load balancing in 185, 188–200
base station energy sharing problem
197
BPO problem, approximation solution
191–193
convergence and optimality 195–196
energy model 189–190
performance evaluation 197–200
problem decomposition 192–193
problem formulation 190–191
traffic model 189
weighted user–BS association (WUA)
problem 193–195
SoftRAN. See Software-defined radio access network
Software-defined radio access network
(SoftRAN) 138, 144
Solar energy 92
Spatial spectrum sharing 38–39
SPCM. See Simplified PCM
Spectrum
access 37
allocation 34, 38–39
analysis 33, 34–37
handover 33–34, 37–38
management 33–34, 37–38
mobility 37–38
sensing 33, 34–37
sharing 34, 38–39
Spectrum harvesting techniques 33
for dynamic spectrum access 34
energy efficiency in 34
allocation and sharing 38–39
cooperative cognitive radio for 39–42
enhancing 39–43
green cognitive small cells for 42–43
green relaying for 39–42
management and handover 37–38
sensing and analysis 34–37
functions
allocation and sharing 34
management and handover 33–34
sensing and analysis 33
SSF. See Strongest-signal first
Static power consumption 26
BS 142, 189–190
GCB 223–224
MBS 113
PBS 65, 72
relay node’s 213–214
SBS 111
Strongest-signal first (SSF) method 135–138
Super-aggregation, mobile data offloading 266
TCP
concurrency 243
congestion window 251–252
connections 243
flaws 242
TCP ACK compression 243
TCP slow start 242–243
optimization 251
ACK mechanisms 261
TCP-Mobile Edge (ME) 252–261
transmission control mechanisms 251–252
TCP-Mobile Edge (ME) 252–261
TCP-NR. See TCP-network coding
TCP-network coding (TCP-NR) 250–251
TCP-Vegas 250–251
TDMA. See Time division multiple access
Temporal spectrum sharing 38, 39
Time division multiple access (TDMA) 20
TOM. See Traffic offloading maximization
Traffic load balancing
in backhaul constrained SCNs 165–185
cell range expansion technique for 130
ergy- and QoS-aware 138–165
energy model 141–142
problem formulation 143–144
traffic model 139–141
dGALA 144–165
in heterogeneous networking (HetNet) 129–131
in mobile networks 129–131
network utilities for 166
in smart grid enabled mobile networks 185–200
Traffic offloading
heuristic 205, 226–232
maximization problem 205
mobile 6
ad-hoc based 6, 7
energy and spectrum efficient 61–90
infrastructure based 6, 7
ISP and 61
user–BS associations in heterogeneous mobile networks 7–8
power efficiency of 193
Traffic offloading maximization (TOM) problem 205

U
UEs. See User equipment
UMTS. See Universal mobile telecommunication system
Universal mobile telecommunication system (UMTS) network 240
User–BS association problem 8
User equipment (UE) 7, 8
User mobility 244
User plane protocol 57–58

V
vGALA. See virtual Green energy Aware and Latency Aware
Video applications, data traffic volume and 239
virtual Green energy Aware and Latency Aware (vGALA) scheme 144–145
admission control mechanism 154–155
BS side algorithm 146–147
convergence of 147–150
energy–latency trade-off adaptation 154
generalization 151–152
optimality 150–151
performance, evaluation of 155–156
adaptation 159–161
comparison 156–159
green energy generation rate 161–164
practicality evaluation 164–165
practical implementation of 153–154
user side algorithm 145–146

W
WAN. See Wide area network
WebAccel 268–269
Web content delivery acceleration
system 266–267
Chameleon 271
GPRSWeb 267–268
Macara platform 270
Nett-Gain 269–270
NPS 270
pTHINC 271
Silo 271–272
WebAccel 268–269
Web page layout adaptation 263
Wide area network (WAN) 241
WiFi hot spots 7, 61
WiFi networks 7
Winning bid selection algorithm 75–76
Wireless loss alarm (WLA) bit 252
Wireless multicasting 205
gradient guided algorithm 206–207
performance evaluation 207–212
problem formulation 205–206
system model 205–206
WLA. See Wireless loss alarm

Y
YouTube 239

Z
Zero grid electricity networking 111–112