GREEN COMMUNICATIONS

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PRINCIPLES, CONCEPTS AND PRACTICE

Edited by

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Preface

Energy efficiency and green communications aim at addressing the quest for sustainability regarding power resources and environmental conditions. For telecommunication service providers, energy efficiency merely means cost reduction, in terms of capital and operational expenditures. For government bodies and regulators, energy efficiency and green communications is a duty to strengthen corporate responsibility towards the environment and motivate an ecological generation of network equipment and systems.

Energy efficiency evolved into a significant parameter of equipment design, architecture and management of telecommunication systems but has not been taken into account until the Kyoto Protocol early in 1997, which raised concerns regarding global warming. Initial efforts concentrated on network edge equipment and peripherals, communication protocols and then progressively on wireless radio and cellular systems as well as on fixed networks. Nowadays, after a steep increase of studies, innovation and practice, energy efficiency and green communications are entering a mature phase, with established solutions addressing particular aspects of a telecommunication system.

Despite such momentum, the potential for energy conservation is still huge especially since advanced services and applications are increasing the complexity of network usage and the demand for enhanced capacity, speed and network resources, driving the growth of network infrastructure deployment. In addition, such earlier approaches prepared the ground for further advance contributions that consider different equipment design features, a combination of communication protocols and holistic network mechanisms that are more sophisticated and comprehensive since they take into account several diverse aspects and cross-layer issues of a telecommunication system.

In structuring the material contained in this book, our goal is to elaborate the fundamentals of energy efficiency and green communications exploring the main challenges, mechanisms and practice considering both wireless and wireline systems. Wireless and wireline communications are organized into two different corresponding sections that address equipment, management, architecture, communication protocols, applications and different deployment aspects. Each chapter is organized in a tutorial nature that contains well-established solutions and the main associated findings in a way that is easy for the reader to follow, providing also a list of references for the interested reader to explore further. In closing each section, a dedicated chapter summarizes the current advances related to the main standardization bodies and list all related specifications and studies in an effort to enhance the view of the reader regarding the adoption and exploitation of such research technologies into industry products and solutions and to provide the basics for standardization engineers who wish to enter the field.

Often a choice had to be made about including certain concepts, evolving research areas and mechanisms, but given the limited space, the focus remained on material that enable the reader to understand the basics in order to innovate the development of more advance solutions. We hope that this book can serve the reader as a first orientation and as a tool for experts to dive deeper into this new vigorous and fascinating area.

Konstantinos Samdanis
NEC Europe Ltd

List of Abbreviations

1G	1st Generation of wireless telephone technology
2G	2nd Generation of wireless telephone technology
3G	3rd Generation of mobile telecommunications
3GPP	3rd Generation Partnership Project (3GPP)
3GPP2	3rd Generation Partnership Project 2
4G	4th Generation of mobile telecommunications
5G	5th Generation of mobile telecommunications
AAA	Authentication Authorization Accounting
AC-DC	Alternating Current –Direct Current
ACI	Adjacent Channel Interference
ACPI	Advanced Configuration and Power Interface
ADC	Analogue to- digital converter
ADSL	Asymmetric Digital Subscriber Line
A-ESR	Ant colony based-Energy Saving Routing
AF	Amplify-and-Forward
ALR	Adaptive Link Rate
ALTO	Application Layer Transport Optimization
AMC	Adaptive Modulation and Coding
AMR	Automatic Meter Reader
AON	Active Optical (access) Network
AP	Access Point
API	Application Program Interface
APP	Application
ARP	Address Resolution Protocol
ARPU	Average Revenue Per User
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Asynchronous Transfer Mode
AUC	Authentication Centre
AWGN	Additive White Gaussian Noise
BAN	Body Area Network
BB	Baseband
BBF	Broadband Forum,
BCCH	Broadcast Control Channel
BBU	Baseband Unit

BLE	Bluetooth Low Energy
BS	Base Stations
BSC	Base Station Controller
BER	Bit Error Rate
BSS	Basic Service Set
BTS	Base Station Sites
CAGR	Compound Annual Growth Rate
CAPM	Context-Aware Power Management
CAPEX	Capital Expenditure
CCN	Content-Centric Networking
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CDN	Content Distribution Network
CLI	Convergence Layer Interface
CN	Core Network
CO	Central Offices
CoC	Code-of-Conduct
CoMP	Coordinated Multi-Point
COPSS	Content-Oriented Publish/Subscribe System
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
CPU	Central Processing Unit
CR	Cognitive Radio
CR mode	Continuous Reception mode
CS	Cell zooming Server
CSI	Channel State Information
CTMC	Continuous-Time Markov Chain
CUBS	Coordinated Upload Bandwidth Sharing
D2D	Device-to-Device
DA	Dynamic Adaptation
DC	Data Center
DAC	Digital-to-Analogue Converter
DAG	Data Acquisition and Generation
DAISIES	Distributed and Adaptive Interface Switch off for Internet Energy Saving
DDoS	Distributed Denial-of-Service attack
DE	Deployment Efficiency
DER	Distributed Energy Resource
DF	Decode-and-Forward
DHCP	Dynamic Host Configuration Protocol
DiR	Differentiated Reliability
DLC	Digital Loop Carrier
DNS	Domain Name Systems
DP	Dynamic Programming
DPA	Doherty Power Amplifiers
DPD	Digital Pre-Distortion
DR	Demand Response

DRAM	Dynamic Random-Access Memory
DRX	Discontinuous Reception
DSP	Digital Signal Processing
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer
DTIM	Delivery Traffic Indication Message
DTN	Delay Tolerant Network
DTX	Discontinuous Transmission
DWDM	Dense Wavelength Division Multiplexing
EASes	Energy-Aware States
EAT	Energy-Aware Traffic engineering
EA-RWA	Energy-Aware RWA
EC	European Commission
ECI	Energy Consumption Index
ECR	Energy Consumption Ratio
EDGE	Enhanced Data Rates for GSM Evolution
EE	Energy Efficiency
EEE	Energy-Efficient Ethernet
EEF	Energy Efficiency Factor
EEER	Equipment Energy Efficiency Ration
EIA-RWA	Energy and Impairment aware RWA
EIR	Equipment Identity Register
EIRP	Effective Isotropic Radiated Power
EMAN	Energy Management
eNB	evolved Node B
EPAR	Energy Profile Aware Routing
EPC	Evolved Packet Core
EPON	Ethernet passive optical network
ERG	Energy Reduction Gain
ES	Energy Saving
ESACON	Energy Saving based on Algebraic Connectivity
ESIR	Energy-Saving IP Routing Strategy
ES-TE	Energy-Saving Traffic Engineering
ESM	Energy Saving Management
ETG	Energy Throughput Gain
ETSI	European Telecommunication Standardization Institute
eUTRAN	Evolved Universal Terrestrial Radio Access Network
EV-DO	Evolution-Data Optimized
FE	Forwarding Element
FIB	Forwarding Information Base
FTP	File Transfer Protocol
FFT/iFFT	Fast Fourier Transform/inverse Fast Fourier Transform
FTTH	Fiber To The Home
FSU	Femto SU
FWM	Four Wave Mixing
GABS	Gradient Assisted Binary Search

GAL	Green Abstraction Layer
GBNB	Green Backbone Networks with Bundled links
GEPON	Gigabit Ethernet PON
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GHG	Global Greenhouse Gas
GMPLS	Generalized MPLS
GMTE	Green MPLS Traffic Engineering
GPON	Gigabit Passive Optical Network
GPS	Global Positioning System
GPRS	General packet radio service
GR	Green Radio
GRiDA	Green Distributed Algorithm
GreenTE	Green Traffic Engineering
GSI	Green Standard Interface
GSM	Global System for Mobile
GSMA	GSM Association
GtCO2e	Gigatons of CO2 equivalent
GTP	GPRS Tunneling Protocol
HARQ	Hybrid-Automatic Repeat Request
H2H	Human-to-Human
HDD	Hard Disk
HDLC	High-level Data Link Control
HetNet	Heterogeneous Networks
H-GW	Home Gateway
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HW	Hardware
IA-RWA	Impairment Aware-RWA
ICMP	Internet Control Message Protocol
ICN	Information Centric Networking
ICT	Information Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IL	Idle Logic
ILP	Integer Linear Programming
IMPEX	Implementation expenses
IoT	Internet of Things
IP	Internet Protocol
IRTF	Internet Research Task Force
ISD	Inter-Site Distance
IT	Information Technology
ITU	International Telecommunication Union
ISIS	Intermediate System to Intermediate System

ISP	Internet Service Providers
KPI	Key Performance Indicators
LAN	Local Area Network
LC	Line Card
LCA	Life Cycle Assessment
LCPs	Local Control Policies
LFA	Least Flow Algorithm
LLDP	Link Layer Discovery Protocol
LNA	Low-Noise Amplifier
LoM	LAN on Motherboard
LPI	Low Power Idle
LSDB	Link State Database
LSI	Large-Scale Integration
LSP	Label Switched Paths
LTE	Long-Term Evolution
LTE-A	LTE-Advanced
M2M	Machine-to-Machine
MAC	Medium Access Control
MAN	Metropolitan Area Network
MCFP	Maximum Conditional Failure Probability
MCS	Modulation and Coding Scheme
MGW	Media Gateway
MIB	Management Information Base
MILP	Mixed-Integer Linear Programming
MIMO	Multiple-Input-Multiple-Output
MME	Mobility management Entity
mm-wave	millimeter-wave
MNO	Mobile Network Operator
MPA	Most Power Algorithm
MPLS	Multi-Protocol Label Switching
MSAN	Multi-Service Access Node
MSC	Mobile Switching Centre
MSU	Macro SU
MU-MIMO	Multiuser-MIMO
MSAN	Multi-Service Access Node
MTC	Machine Type Communications
MU	Mobile User
NAPS	Non-intrusive location-Aware Power management Scheme
NAS	Non-Access Stratum
NAT	Network Address Translation
NCM	Network Control Module
NCP	Network Connectivity Proxy
NCPs	Network-wide Control Policies
ND	Network Device
NDN	Named Data Networking
NFV	Network Function Virtualization

NGMN	Next Generation Mobile Network
NIC	Network Interface Card
NM	Network management
NoA	Notice of Absence
NW	Network
OAM	Operation, Administration and Maintenance
OCP	Optical Control Plane
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OLT	Optical Line Terminal
ONU	Optical Network Unit
OPEX	Operating Expenditure
OS	Operating System
OSP	Optimization Service Protocol
OSPF	Open Shortest Path First
OSPF-TE	Open Shortest Path First-Traffic engineering
OSI	Open Systems Interconnection
OTN	Optical Transport Network
P2P	Peer-to-Peer
PA	Power Amplifier
PAPR	Peak-to-Average Power Ratio
PC	Personal Computer
PCE	Path Computation Element
PCRF	Policy and Charging Rules Function
PD	Powered Device
PDA	Personal Digital Assistant
PDCP	Packet Data Convergence Protocol
PDH	Plesiochronous Digital Hierarchy
PDN GW	Packet Data Network -Gateway
PDP	Packet Data Protocol
PDU	Power Distribution Unit
PIT	Pending Interest Table
PLC	Power Line Communication
PLI	Physical Layer Impairments
PLMN	Public Land Mobile Networks
PMP	Power Management Primitives
PS	Packet Switching
PSE	Power Source Equipment
PSIRP	Publish Subscribe Internet Routing Paradigm
PS-Poll	Power Save Poll
PSM	Power Saving Mode
PtP	Point-to-Point
RE	Resource Element
PHY	Physical
RN/RS	Relay Nodes/Relay Stations
PoE	Power over Ethernet

PON	Passive Optical Network
PPP	Point-to-Point Protocol
ProSe	Proximity Services
PSU	Power Supply Unit
PU	Primary User
PUA	Power per Unit Area
PUE	Power Usage Effectiveness
QoE	Quality of Experience
QoS	Quality of Service
QoT	Quality of Transmission
RAN	Radio Access Network
RAR	Random Access Response
RAT	Radio Access Technology
RAU	Routing Area Update
RF	Radio Frequency
RFID	Radio Frequency Identification
RH	Radio Head
RLC	Radio Link Control
RNC	Radio Network Controller
RoD	Resources-on-Demand
RP	Router Processor
RPT	Reverse Path Tree
RRC	Radio Resource Control
RRH	Remote Radio Head
RSSI	Received Signal Strength Indicator
RTPGE	Reduced Twisted Pair Gigabit Ethernet
RSVP-TE	Resource Reservation Protocol - Traffic Engineering
RWA	Routing and Wavelength Assignment
Rx	Receiver
SCaaS	Small Cells as a Service
SC-FDMA	Single Carrier - Frequency Division Multiple Access
SDH	Synchronous Digital Hierarchy
SDN	Software-Defined Network
SDO	Standards Development Organizations
SE	Spectral Efficiency
SGW	Serving Gateway
SIEPON	Service Interoperability in Ethernet Passive Optical Networks
SINR	Signal-to-Interference-and-Noise Ratio
SIP	Session Initiation Protocol
SIR	Signal-to-Interference Ratio
SISO	Single-Input-Single-Output
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol
SON	Self-Organizing Network
SONET	Synchronous Optical Networking
SSR	Sleep Server

ST	Subscription Table
SU	Secondary User
SU-MIMO	Single-User MIMO
TA	Timing Alignment
TAU	Tracking Area Update
TDM	Time Division Multiplexing
TE	Traffic Engineering
TIA	Transimpedance Amplifier
TCAM	Ternary Content Addressable Memory
TCP/IP	Transmission Control Protocol/Internet Protocol
TEER	Telecommunications Energy Efficiency Ratio
TLB	Table Lookup Bypass
TLS	Transport Layer Security
TPG	Throughput Gain
TTU	Transmission Time Unit
TVWS	TV White Spectrum
TWT	Target Wake Time
Tx	Transmitter
U-APSD	Unscheduled Automatic Power Save Delivery
UE	User Equipment
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
UPC	Uplink Power Control
UPnP	Universal Plug and Play
URI	Uniform Resource Identifier
UTP	Unshielded Twisted Pair
UTRAN	Universal Terrestrial Radio Access Network
UWB	Ultra-Wideband
VLAN	Virtual LAN
VM	Virtual Machine
VoIP	Voice over IP
VPN	Virtual Private Network
WCDMA	Wideband Code Division Multiple Access
WDM	Wavelength Division Multiplexing
WFA	Wi-Fi Alliance
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless LAN
WoL	Wake-on-LAN
WPA-OR	Weighted Power-Aware Optical Routing
WSS	Wavelength selective switch
WXC	Wavelength Cross Connect
XPM	Cross Phase Modulation