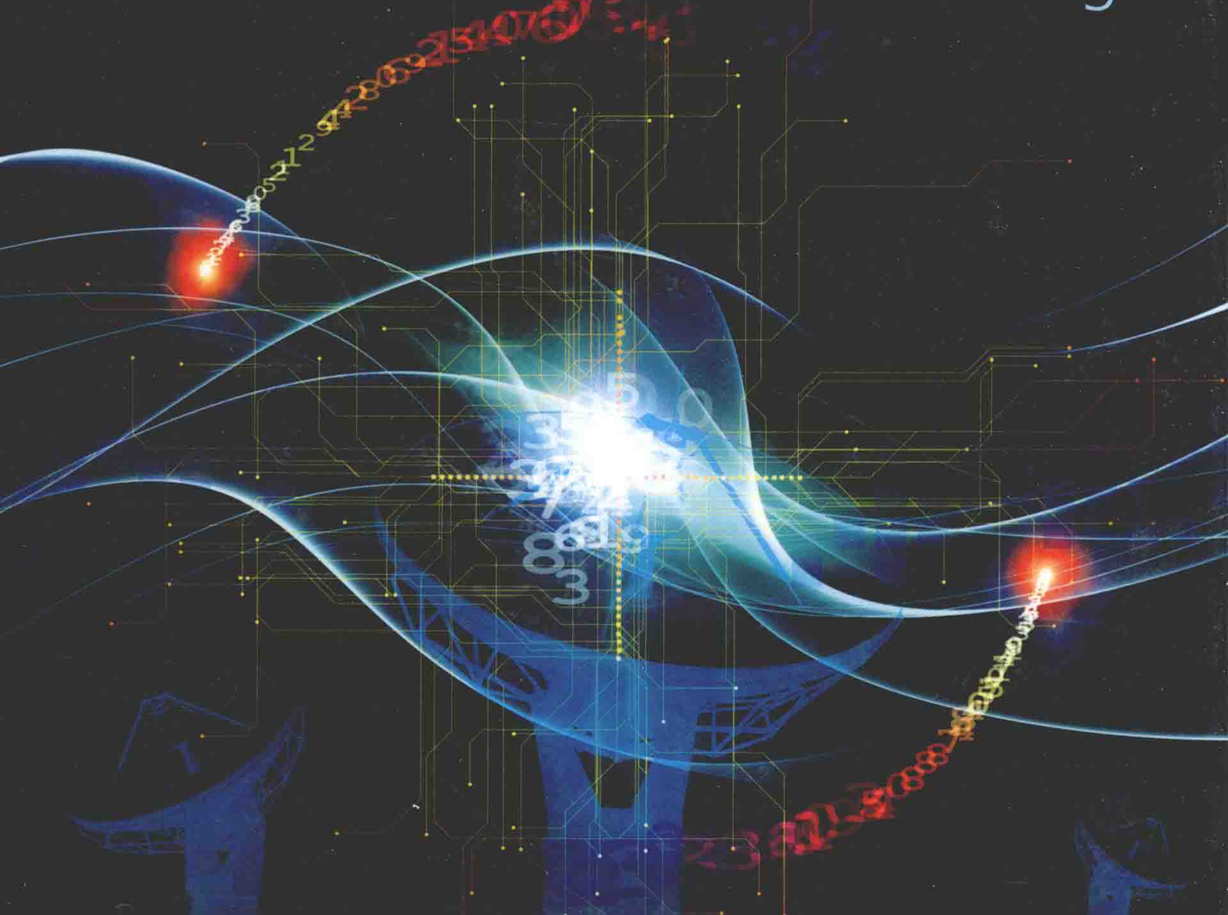
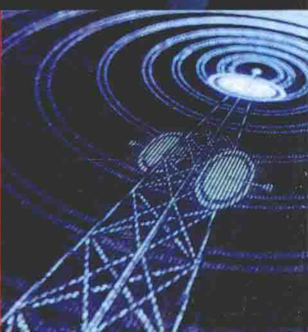
G. Keith Cambron

Global Networks

Engineering, Operations and Design





WILEY

IEEE
IEEE PRESS

GLOBAL NETWORKS
ENGINEERING, OPERATIONS AND DESIGN

G. Keith Cambron
Former President and CEO, AT&T Labs (Retired), Texas, USA

IEEE

WILEY
A John Wiley & Sons, Ltd., Publication

This edition first published 2013

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

Library of Congress Cataloging-in-Publication Data

Cambron, G. Keith.
Global networks : engineering, operations and design / G. Keith Cambron.
pages cm
Includes bibliographical references and index.
ISBN 978-1-119-94340-2 (hardback)
1. Wireless communication systems. 2. Telecommunication. 3. Globalization. I. Title.
TK5103.C36 2012
384.5–dc23

2012022584

A catalogue record for this book is available from the British Library.

ISBN: 9781119943402

Typeset in 10/12pt Times by Laserwords Private Limited, Chennai, India.

Printed and bound in Malaysia by Vivar Printing Sdn Bhd

1 2012

GLOBAL NETWORKS

Dedicated to Amos E. Joel, Jr
and the Members of the Technical Staff
at AT&T Labs and SBC Labs

About the Author

Keith Cambron has a broad range of knowledge in telecommunications networks, technology and design and R&D management. His experience ranges from circuit board and software design to the implementation of large public networks.

Keith served as the President and CEO of *AT&T Labs, Inc*. AT&T Labs designs AT&T's global IP, voice, mobile, and video networks. Network technology evaluation, certification, integration, and operational support are part of the Lab's responsibilities. During his tenure AT&T Labs had over 2000 employees, including 1400 engineers and scientists. Technologies produced by Labs ranged from core research to optical transport, IP routing, voice, and video systems.

2003 to 2006 – Cambron served as the President and CEO of *SBC Laboratories, Inc*. The organization, which set the strategic technology objectives of SBC, was structured into four technology areas; Broadband, Wireless, Network Services, and Enterprise IT. SBC Labs led the industry in the introduction of VDSL and IPTV technologies.

1998 to 2003 – Cambron was principal of *Cambron Consulting*, where he provided network and software design consulting services to the telecommunications industry. Working with clients such as SBC, Vodafone Wireless, Coastcom and various enterprise networks, Cambron designed and developed network management systems, a wireless Short Messaging Service (SMS) server, a Service Switching Point (SSP), and an ADSL transmission performance optimization system.

1987 to 1997 – Cambron held leadership positions at *Pacific Bell Broadband*, acting as the chief architect of a network engineering team that developed a 750 MHz hybrid fiber/coax-based network. For this project, Cambron received Telephony's "Fiber in the Loop" design award.

His career started at *Bell Telephone Laboratories* in 1977, where he began as a member of the technical staff. He advanced to Director of Local Switching Systems Engineering and led a team to design automated verification test tools for local digital switch testing. Cambron went on to become Director of Network Systems Verification Testing at *Bell Communications Research*, heading field verification teams in all seven Regional Bell Operating Companies to test "first in nation" technologies, including the first local digital switching systems.

Cambron has been profiled in *Telephony and America's Network*, and has published in *IEEE Communications* and *Proceedings of the IEEE*. He taught Object Oriented Design at Golden Gate University in San Francisco and is a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE).

In 2010, Cambron was named by *CRN Magazine* as one of the Top 25 Technology Thought-Leaders in the world. Keith received IEEE Communications Society's Chairman's Communication Quality and Reliability Award in 2007. He holds ten patents for telecommunications software and systems he designed and deployed.

Cambron received his BS in Electrical Engineering from the University of Missouri, an MS in Systems Management from the University of Southern California, and a Programming Certification from the University of California at Berkeley. He is a retired Commander in the United States Naval Reserve.

Foreword

Networks today are like the air we breathe, so ubiquitous we often take them for granted and in fact don't even realize they're there. Whether we are working, studying, communicating or being entertained, we rely on networks to make whatever we need to happen, happen. This trend is increasing as networks become more and more powerful and reach more deeply into the fabric of our lives.

This reach is not limited to just the wealthy or to developed nations, however, as lower costs and higher capacity extend the power of networks to citizens all around the globe. *That's what makes this book so relevant and so timely*. A clear understanding of these networks is essential for those that would design, construct, operate and maintain them. As Keith points out early in this volume, the growing gap between the academic description of networks and the real world design and operation of these networks, is a key divide that needs bridging. And Keith is in a unique position to do this.

I've known Keith for over 15 years, and have always found him to be a fascinating and indeed remarkable man. His curiosity and intelligence, coupled with a career so deeply involved in network design at AT&T has given him the tremendous insight that he shares in this book. Keith has never been afraid to step outside the accepted norm, if he felt the need, for pursuit of a new area of excellence. This is what makes his knowledge and understanding so valuable and drives the core of this work.

Looking forward, Moore's Law will continue to enable the exponential growth of the value of the underlying technologies, namely processing, memory and optical communications speed, that make these networks tick. The resultant capabilities of the next generations of networks, five years or a decade out, are virtually indescribable today! That in the end is what makes this book so valuable – a thorough understanding of the design principles described herein will allow those that shape our networks in the future to "get it right," enhancing our lives in ways we cannot begin to imagine.

Robert C. McIntyre
Chief Technical Officer, Service Provider Group
Cisco Systems

Preface

When I began my career in telecommunications in 1977 at Bell Telephone Laboratories two texts were required reading, *Engineering and Operations in the Bell System* [1] and *Principles of Engineering Economics* [2]. Members of Technical Staff (MTS) had Masters or PhDs in engineering or science but needed grounding in how large networks were designed and operated, and how to choose designs that were not only technically sound, but economically viable. As the designers of the equipment, systems and networks, engineers at Bell Labs were at the front end of a vertically integrated company that operated the US voice and data networks. Operational and high availability design were well developed disciplines within Bell Labs, and network systems designs were scrutinized and evaluated by engineers practicing in those fields. So ingrained in the culture was the operational perspective, that engineers and scientists were strongly encouraged to rotate through the Operating Company Assignment Program (OCAP) within the first two years of employment. During that eight week program engineers left their Bell Labs jobs and rotated through departments in a Bell Telephone Operating Company, serving as operators, switchmen, installers and equipment engineers. OCAP was not restricted to engineers working on network equipment; members of Bell Labs Research participated in the program. AT&T was not alone in recognizing the value of operational and reliability analysis in a vertically integrated public telephone company, Nippon Telephone and Telegraph, British Telecom, France Telecom and other public telephone companies joined together in technical forums and standards organizations to codify operational and high availability design practices.

After 1982 regulatory, technology and market forces dramatically changed the way networks and systems were designed and deployed. Gone are vertically integrated franchise operators, replaced by interconnected and competing networks of carriers, equipment and systems suppliers, and integrators. Innovation, competition and applications are the engines of change; carriers and system suppliers respond to meet the service and traffic demands of global networks growing at double and even triple digit rates, carrying far more video content than voice traffic. Consumer and enterprise customers are quick to adopt new devices, applications and network services; however, when legacy carriers deliver the service the customers' expectations for quality and reliability are based on their long experience with the voice network. The industry has largely delivered on those expectations because an experienced cadre of engineers from Bell Labs and other carrier laboratories joined startups and their spun off suppliers like Lucent and Nortel. But as time passes, the operational skill reservoir recedes not only because the engineers are retiring, but because of the growing separation between engineers that design and operate networks, and those that design equipment, systems and applications that enter the network. The clearest example of the change is the influx of IT trained software engineers into the fields of network applications and systems design. Experience in the design of stateless web applications or financial systems are insufficient for the non-stop communication systems in the network that continue to operate under a range of hardware faults, software faults and traffic congestion.

My own journey gave me a front row seat through the transformation from a regulated voice network to a competitive global IP network. As a systems engineer in the 1970s I worked on call processing requirements and design for the No. 1 ESS. In the 1980s I led teams of test and verification engineers in the certification of the DMS-10, DMS-100, No. 5ESS, No. 2 STP, DMS STP and Telcordia SCP. I also led design teams building integrated test systems for Signaling System No. 7 and worked for startup companies designing a DS0/1/3 cross connect system and a special purpose tandem switching system. During the last eight years I headed SBC Labs and then AT&T Labs as President and CEO. Working with engineers across network and systems, and spending time with faculty and students at universities I became aware of the growing gap in operational design skills. Universities acknowledge and reward students and faculty for research into theoretical arenas of network optimization and algorithm design. Their research is seldom based on empirical data gathered from networks, and rarer still is the paper that actually changes the way network or systems operate. I chose to write this book to try and fill some of that void. My goal is to help:

- those students and faculty interested in understanding how operational design practices can improve system and network design, and how networks are actually designed, managed and operated;
- hardware and software engineers designing network and support systems;
- systems engineers developing requirements for, or certifying network equipment;
- systems and integration engineers working to build or certify interfaces between network elements and systems;
- operations support systems developers designing software for the management of network systems; and
- managers working to advance the skills of their engineering and operating teams.

The book is organized into three parts; *Networks*, *Teams and Systems*, and *Transformation*. It is descriptive, not prescriptive; the goal is not to tell engineers how to design networks but rather describe how they are designed, engineered and operated; the emphasis is on engineering and design practices that support the work groups that have to install, engineer and run the networks. Areas that are not addressed in the book are network optimization, engineering economics, regulatory compliance and security. Security as a service is described in the chapter on cloud services but there are several texts that better describe the threats to networks and strategies for defense [3, 4].

References

1. *Engineering and Operations in the Bell System*, 1st edn, AT&T Bell Laboratories (1977).
2. Grant, E.L. and Ireson, W.G. (1960) *Principles of Engineering Economy*, Ronald Press Co., New York.
3. Cheswick, W.R. Bellovin, S.M. and Rubin, A.D. (2003) *Firewalls and Internet Security*, 2nd edn, *Repelling the Wily Hacker*, Addison Wesley.
4. Amoroso, E. (2010) *Cyber Attacks: Protecting National Infrastructure*, Butterworth-Heinemann, November.

Acknowledgments

The technical breadth of this text could not have been spanned without the help of engineers I have had the privilege of working with over the years. While I researched and wrote the entire text, these contributors were kind enough to review my material. I am grateful for the contributions of John Erickson, Mike Pepe, Chuck Kalmanek, Anthony Longhitano, Raj Savoor, and Irene Shannon. Each reviewed specific chapters that cover technology within their area of expertise and corrected my technical errors and omissions. They are not responsible for the opinions and projections of future technology trends, and any remaining errors are mine.

I also want to thank the team at John Wiley & Sons, Ltd for guiding me through the writing and publishing process. They made the experience enjoyable and their professional guidance kept me on a sure track.

List of Acronyms

10G	10 Gigabit
100G	100 Gigabit
10GEPON	10 Gigabit Ethernet Passive Optical Network
21CN	21st Century Network
3G	Third Generation Mobile Technology
3GPP	Third Generation Partnership Project
4G	Fourth Generation Mobile Technology
40G	40 Gigabit
400G	400 Gigabit
6rd	IPv6 Rapid Deployment
AAAA	Quad A DNS Record
ABR	Available Bit Rate
ACD	Automatic Call Distributor
ACM	Address Complete Message (ISUP)
ADL	Advanced Development Lab
ADM	Add-Drop Multiplexer
ADPCM	Adaptive Differential Pulse Code Modulation
ADSL	Asymmetric Digital Subscriber Line
ADSL1	Asymmetric Digital Subscriber Line G.992.1 standard
ADSL2+	Asymmetric Digital Subscriber Line G.992.5 standard
AIN	Advanced Intelligent Network
AINS	Automatic In-Service
AIS	Alarm Indication Signal
ALG	Application Level Gateway
ALI	Automatic Line Identification
AMI	Alternate Mark Inversion
AMPS	Advanced Mobile Phone Service
AMR	Adaptive Multi-Rate
API	Application Programming Interface
APN	Access Point Name
APS	Automatic Protection Switching
ARGN	Another Really Good Network
ARP	Address Resolution Protocol
AS	Autonomous System

AS	Application Server
ASON	Automatic Switched Optical Network
ASP	Application Service Provider
AT	Access Tandem
ATA	Analog Terminal Adapter
ATCA	Advanced Telecommunications Computing Architecture
ATM	Asynchronous Transfer Mode
ATSC	Advanced Television Systems Committee
AUMA	Automatic and Manual Service State
AWG	American Wire Gauge
AWS	Advanced Wireless Services
BCP	Business Continuity Plan
BCPL	Basic Combined Programming Language
BGCF	Breakout Gateway Control Function
BGF	Border Gateway Function
BGP	Border Gateway Protocol
BITS	Building Integrated Timing Supply
BLSR	Bi-directional Line Switched Ring
BORSCHT	Battery, Over-voltage, Ringing, Supervision, Codec, Hybrid, Testing
BPON	Broadband Passive Optical Network
BRAS	Broadband Remote Access Server
BRI	Basic Rate Interface (ISDN)
BSC	Base Station Controller
BSD	Berkeley Software Distribution
BSS	Business Support System
BSSMAP	Base Station Subsystem Mobile Application Part
BT	British Telecom
BTL	Bell Telephone Laboratories
BTS	Base Transceiver Station
CALEA	Communications Assistance for Law Enforcement Act
CAMEL	Customized Applications for Mobile network Enhanced Logic
CAS	Channel Associated Signaling
CAT3	Category 3, refers to a grade of twisted pair cable
CATV	Community Antenna Television
CBR	Constant Bit Rate
CCAP	Converged Cable Access Platform
CCIS	Common Channel Interoffice Signaling
CCS	Common Channel Signaling
CDB	Centralized Database
CDF	Charging Data Function
CDMA	Code Division Multiple Access
CDN	Content Delivery Network
CDR	Call Detail Record
CE	Customer Edge
CES	Circuit Emulation Service
CGN	Carrier Grade NAT

CGN64	Carrier Grade NAT IPv6/IPv4
CIC	Carrier Identification Code
CIC	Circuit Identification Code
CLASS	Custom Local Area Signaling Services
CLEC	Competitive Local Exchange Carrier
CLI	Command Line Interface
CLLI	Common Language Location Identifier
CM	Cable Modem
CM	Capacity Management
CMS	Customer Management System
CMTS	Cable Modem Termination System
CNAM	Calling Name Service
CO	Central Office
CONF	Conference Services
CORBA	Common Object Request Broker Architecture
CoS	Class of Service
CPE	Customer Premises Equipment
CPU	Central Processing Unit
CR	Constrained Routing
CRC	Cyclic Redundancy Check
CRS	Carrier Routing System
CSCF	Call Session Control Function
CSFB	Circuit Switched Fallback
CSS3	Cascading Style Sheet 3
CTAG	Command Tag
CURNMR	Current Noise Margin
DA	Distribution Area
DAML	Digitally Added Main Line
DARPA	Defense Advanced Research Projects Agency
DAS	Directed Antenna System
DBMS	Database Management System
DBOR	Database of Record
DCC	Data Communications Channel
DCS	Digital Cross Connection System
DHCP	Dynamic Host Control Protocol
DHCP6	Dynamic Host Control Protocol for IPv6
DLC	Digital Loop Carrier
DLNA	Digital Living Network Alliance
DMS	Digital Multiplex System
DMT	Discrete Multitone
DMTS	Distinguished Member of Technical Staff
DNS	Domain Name System
DNS64	Domain Name System for IPv4 and IPv6
DOCSIS	Data Over Cable Service Interface Specification
DoS	Denial Of Service
DPM	Defects Per Million

DSBLD	Disabled Service State
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Dynamic Spectrum Management
DSP	Digital Signal Processor
DSTM	Dual Stack IPv6 Transition Mechanism
DSX	Digital Cross Connect
DTAP	Direct Transfer Application Part (SS7)
DTV	Digital Television
DVB	Digital Video Broadcast
DVD	Digital Video Disc
DVR	Digital Video Recorder
DWDM	Dense Wave Division Multiplexing
E911	Enhanced 911
EADAS	Engineering Admin Data Acquisition System
EDFA	Erbium Doped Fiber Amplifier
EDGE	Enhanced Data Rates for Global Evolution
EFM	Ethernet in the First Mile
EGP	External Gateway Protocol
EIGRP	Enhanced Interior Gateway Routing Protocol
EMEA	Europe, the Middle East and Africa
EMS	Element Management System
ENUM	E.164 Number Mapping
EOC	Embedded Operations Channel
EPON	Ethernet Passive Optical Network
ESAC	Electronic Systems Assurance Center
ESME	External Short Messaging Entity
ESS	Electronic Switching System
eTOM	Enhanced Telecom Operations Map
ETS	Electronic Translator System
FCAPS	Fault, Configuration, Accounting, Performance, Security
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FEC	Forwarding Equivalent Class
FEXT	Far End Crosstalk
FOU	Field of Use
FRR	Fast Reroute
FRU	Field Replaceable Unit
FSAN	Full Service Access Network
FTP	File Transfer Protocol
FTTB	Fiber To The Building
FTTC	Fiber To The Curb
FTTH	Fiber To The Home
FTTN	Fiber To The Node

GEM	GPON Encapsulation Method
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway General Packet Radio Services Support Node
GMPLS	Generalized Multi-protocol Label Switching
GMSC	Gateway Mobile Switching Center
GMSK	Gaussian Minimum Shift Keying
GNOC	Global Network Operations Center
GPON	Gigabit Passive Optical Network
GPS	Global Positioning System
GRE	Generic Routing Encapsulation
GRX	GPRS Routing Exchange
GSM	Global System for Mobile Communications
GTP	GPRS Tunneling Protocol
GTT	Global Title Translation
HD	High Definition
HDSL	High Bitrate Digital Subscriber Line
HDTV	High Definition Television
HFC	Hybrid Fiber Coax
HLR	Home Location Register
HPNA	Home Phone line Networking Alliance
HR	Human Resources
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
HVAC	Heating, Ventilation and Air Conditioning
IAM	Initial Address Message (SS7)
IAS	Internet Access Service
IBCF	Interconnection Border Control Function
ICMP	Internet Control Message Protocol
IDL	Interface Definition Language
IGMP	Internet Group Management Protocol
IGP	Interior Gateway Protocol
ILEC	Incumbent Local Exchange Carrier
IM	Instant Messaging
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identifier
IN	Intelligent Network
IOT	Interoperability Testing
IP	Internet Protocol
IPMI	Intelligent Platform Management Interface
IPTV	Internet Protocol Television
IPX	Internet Protocol Packet Exchange

IRAT	Inter-Radio Access Technology
IRSCP	Intelligent Route Service Control Point
IS	In-Service
ISATAP	Intra-Site Automatic Tunnel Addressing Protocol
ISDN	Integrated Services Digital Network
ISP	Internet Services Provider
ISUP	ISDN User Part
IT	Information Technology
ITP	IP Transfer Point
IVR	Interactive Voice Response
IXC	Interexchange Carrier
IXP	Internet Exchange Point
KPI	Key Performance Indicator
LAN	Local Area Network
LATA	Local Access Transport Area
LCP	Local Convergence Point
LD	Long Distance
LDP	Label Distribution Protocol
LEC	Local Exchange Carrier
LEN	Line Equipment Number
LER	Label Edge Router
LERG	Local Exchange Routing Guide
LFIB	Label Forwarding Information Base
LFO	Line Field Organization
LIDB	Line Information Database
LLDP	Local Loop Demarcation Point
LMTS	Lead Member of Technical Staff
LNP	Local Number Portability
LOF	Loss of Frame
LOL	Loss of Link
LOS	Loss of Signal
LP	Link Processor
LPBK	Loop Back
LPR	Loss of Power
LRF	Location Retrieval Function
LRN	Local Routing Number
LSA	Link State Advertisement
LSDB	Link State Database
LSN	Large Scale NAT
LSP	Label Switched Path
LSR	Label Switch Router
LSSGR	LATA Switching System Generic Requirements
LTE	Long Term Evolution
MA	Manual Service State
MAP	Mobile Application Part