WIRELESS COMMUNICATIONS RESOURCE MANAGEMENT

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WIRELESS COMMUNICATIONS RESOURCE MANAGEMENT

To our wives

Hyeon Soon Kang
Joo Yeon Choi
Jong Soon Lee

Preface

Wireless communications, especially in its mobile form, has brought us the freedom of mobility and has changed the lifestyles of modern people. Waiting at a fixed location to receive or make a phone call, or sitting in front of a personal computer to send an e-mail or download a video program, has become an old story. Nowadays it is commonplace for people to talk over a cell phone while walking on the street, or to download and watch a movie while traveling on a train. This is the benefit made available to us by the successful evolution of wireless communications over three generations, with the fourth generation being under way.

Throughout the evolution of wireless communications, enabling technologies have continued to mature and have strived to keep up with satisfying ever increasing customer service expectations. As an example, the multiple-access technique which started from the analog *frequency-division multiple-access* (FDMA) has evolved to digital *time-division multiple-access* (TDMA) and *code-division multiple-access* (CDMA) and has advanced to the sophisticated *orthogonal frequency-division multiple-access* (OFDMA). This in turn has made possible affordable and ubiquitous multimedia services for a large majority of mobile users in both consumer and business sectors.

Notwithstanding the precipitous development of wireless technologies, customers' insatiable desire continues for faster response, larger bandwidth, and more reliable transmission. Unfortunately the desire cannot be easily satiated due to limitations in the wireless communications channels. First of all, the frequency spectrum available for wireless communications is absolutely limited. In addition, the wireless channel characteristics fluctuate due to channel loss, shadowing, and multipath fading phenomena. Furthermore, battery power is a key limitation in mobile communications.

To overcome those limitations in wireless communications and thereby enhance the spectral efficiency, significant research efforts have been exerted on the enabling technologies for the past several decades. Such technologies include *hybrid automatic repeat request* (HARQ) which combines ARQ and *forward error-correction* (FEC) techniques, *adaptive modulation and coding* (AMC) which combines modulation and coding techniques, and various diversity techniques in the time, frequency and space domains. In particular, the *multi-input multi-output* (MIMO) technique is an important multiple antenna technology that takes advantage of space diversity. OFDMA also uses the diversity effect to introduce resilience to multipath fading.

Every time a new generation of wireless communications systems has emerged, it was accompanied by the adoption of more advanced physical layer technologies to achieve enhanced system performance. In the cases of the most recent wireless systems such as Mobile WiMAX and other Advanced International Mobile Telecommunication (IMT) systems, all the above state-of-the-art communication technologies are incorporated as their air interface technologies. With that, we have consumed all the affordable physical layer technologies that communication engineers have discovered/developed to date. For further enhancement of system performance, we can only resort to intelligent and optimal utilization of the available wireless resources. Here comes the need for "wireless communications resource management." In essence, a next-generation wireless communications system can maximize overall system performance only when it adopts the most advanced physical layer technologies *and* optimizes the wireless resource management on top of those technologies.

Basically, wireless resource management determines the optimal use of wireless resources according to the wireless channel information and the *quality-of-service* (QoS) requirements of each user. Specifically, it refers to a series of processes that determine the time, order, procedure, and the amount of wireless resources to allocate to each user in the wireless communications system.

In the context of resource management, the most fundamental three wireless resources are bandwidth, transmission power, and antennas: the available frequency spectrum (and associated channel bandwidth) is limited by both nature and license fees for operators acquiring bandwidth to provision service. Battery power is limited for each mobile device and cost can be an important issue for higher power transmission. Mobile devices are limited in size for placing multiple antennas and need complicated space–time signal processing to operate.

Each available wireless resource is self-limited and the incremental improvement of a wireless resource does not necessarily increase overall system performance. The problem becomes more complicated in the multiuser environment since increasing the transmission power of one user will usually increase interference to other users or to other cells. Thus it is most desirable for wireless resource management to optimally use limited wireless resources to maximize resource efficiency and overall system performance. In effect, optimally managed wireless resources can significantly improve a channel's data rate even with low bandwidth, and also flexibly operate the wireless system, adapting to the channel characteristics and QoS requirements.

This book is intended to provide comprehensive and in-depth discussions on wireless resource management, covering a broad scope, from the provision of preliminary concepts and mathematical tools to the detailed descriptions of all the resource management techniques. It first provides preliminary discussions on the characteristics of wireless channels, basic concepts for wireless resource management problem formulation, and basic mathematical tools such as convex optimization theory useful for solving the wireless resource management problems. Then, it deals with the four different types of resource management in each chapter, namely, bandwidth management, transmission power management, antenna management, and inter-cell resource management. The topics discussed in this book include scheduling, admission control, power control, transmission power allocation, MIMO transmissions, inter-cell interference mitigation, and handoff management, and so on.

The authors believe that the book will help readers gain a thorough understanding of the overall and detailed picture of the wireless communications resource management and deepen their insight into the mechanisms of performance maximization geared by wireless resource management in next-generation wireless communication systems.

An important and useful supplement is available on the book's companion website at the following URL: www.wiley.com/go/bglee.

The authors would like to thank Seoul National University and the Institute of New Media and Communications Research for providing a comfortable environment to write the book, and the students in the Telecommunications and Signal Processing (TSP) laboratory, namely, Soomin Ko, Junho Lim, Seonwook Kim, Sunghan Ryu, Seungmin Lee, and Youngjun Ryu for assisting the writing work in various ways. In addition, the authors would like to deeply thank their wives, Hyeon Soon Kang, Joo Yeon Choi, and Jong Soon Lee, whose love and support enabled the successful completion of this year-long writing project.

About the Authors

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Byeong Gi Lee received the B.S. and M.E. degrees from Seoul National University, Seoul, Korea, and Kyungpook National University, Daegu, Korea, both in electronics engineering, and the Ph.D. degree in electrical engineering from the University of California, Los Angeles. He was with the Electronics Engineering Department of ROK Naval Academy as an Instructor and Naval Officer in active service from 1974 to 1979, and worked for Granger Associates, Santa Clara, CA, as a Senior Engineer responsible for applications of digital signal processing to digital transmission from 1982 to 1984, and for AT&T Bell Laboratories, North Andover, MA, as a Member of Technical Staff responsible for optical transmission system development along with the related standards works from 1984 to 1986. He joined the faculty of Seoul National University in 1986 and served as the Director of the Institute of New Media and Communications in 2000 and the Vice Chancellor for Research Affairs from 2000 to 2002.

Dr Lee was the founding chair of the Joint Conference of Communications and Information (JCCI), the chair of the Steering Committee of the Asia Pacific Conference on Communications (APCC), and the chair of the founding committee of the Accreditation Board for Engineering Education of Korea (ABEEK). He served as the TPC Chair of IEEE International Conference on Communications (ICC) 2005 and the President of Korea Society of Engineering Education (KSEE). He was the editor of the *IEEE Global Communications Newsletter*, an associate editor of *the IEEE Transactions on Circuits and Systems for Video Technology*, and the founding Associate Editor-in-Chief and the Second Editor-in-Chief of the *Journal of Communications and Networks* (JCN). He served for the IEEE Communications Society (ComSoc) as the Director of Asia Pacific Region, as the Director of Membership Programs Development, as the Director of Magazines, as a Member-at-Large to the Board of Governors, and as the Vice President for Membership Development. He served a member of the Presidential Advisory Committee of Policy Planning, the Presidential Advisory Council on Science and Technology, and the Policy Committee of the Ministry of Justice of the Korean Government. He served a Vice President of the ABEEK, the President of Korea Information and Communication Society (KICS), and the first President of the Citizens' Coalition for Scientific Society (CCSS), a non-government organization for the advancement of science and technology in Korea. He currently serves as a Commissioner of the Korea Communications Commission (KCC) and the Vice President for Member Relations of the IEEE ComSoc.

Dr Lee is a co-author of *Broadband Telecommunication Technology*, first and second editions, (Artech House: Norwood, MA, 1993 and 1996), *Scrambling Techniques for Digital Transmission* (Springer Verlag: New York, 1994), *Scrambling Techniques for CDMA Communications* (Kluwer: Norwell, MA, 2001), *Integrated Broadband Networks* (Artech House:

Norwood, MA, April 2002), and *Broadband Wireless Access and Local Networks: Mobile WiMAX and WiBro* (Artech House: Norwood, MA, 2008). He holds thirteen US patents with four more patents pending. His current fields of interest include broadband networks, wireless networks, communication systems, and signal processing.

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Daeyoung Park received the B.S. and M.E. degrees in electrical engineering and the Ph.D. degree in electrical engineering and computer science, all from Seoul National University, Seoul, Korea, in 1998, 2000, and 2004, respectively. He was with Samsung Electronics as a Senior Engineer from 2004 to 2007, contributing to the development of next-generation wireless systems based on the MIMO–OFDM technology. From 2007 to 2008, he was with the University of Southern California, Los Angeles, CA, as a Postdoctoral Researcher. In March 2008, he joined the faculty of the School of Information and Communication Engineering, Inha University, Korea. He received a silver award from Samsung Technical Paper Contest 2005. His research interests include communication systems, wireless networks, multiuser information theory, and resource allocation.

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Hanbyul Seo received the B.S. degree in electrical engineering, and the M.E. and Ph.D. degrees in electrical engineering and computer science, from Seoul National University, Seoul, Korea, in 2001, 2003, and 2008, respectively. He is currently with LG Electronics and his research interests include wireless resource management, wireless MAC protocol, and wireless sensor networks.

Abbreviations

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
ACK	ACKnowledgment
ALP	Active Link Protection
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone System
ARP	Autonomous Reuse Partitioning
ARQ	Automatic Repeat reQuest
AWGN	Additive White Gaussian Noise
BC	Broadcast Channel
BDCL	Borrowing with Directional Channel Locking
BER	Bite Error Rate
BLAST	Bell Labs lAyered Space–Time
BPSK	Binary Phase-Shift Keying
BR	Borrowing from the Richest
BS	Base Station
CBR	Constant Bit Rate
CDF	Cumulative Distribution Function
CDMA	Code-Division Multiple Access
CIF-Q	Channel-condition Independent packet Fair Queueing
CINR	Carrier-to-Interference-and-Noise Ratio
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
CSDPS	Channel State-Dependent Packet Scheduling
CSI	Channel State Information
CSIT	CSI available at Transmitter
CSM	Collaborative Spatial Multiplexing
DCA	Dynamic Channel Allocation
DFT	Discrete Fourier Transform
DL	DownLink
DPC	Distributed Power Control
DPC	Dirty-Paper Coding
DRC	Data Rate Control

D-STTD	Double Space–Time Transmit Diversity
DTR	Dual-Threshold Reservation
EGC	Equal-Gain Combining
EV-DO	Enhanced Version for Data Optimization
EV-DV	Enhanced Version for Data and Voice
EXP	EXP-Q and EXP-W
EXP-Q	EXPonential Queue-length rule
EXP-W	EXPonential Waiting-time rule
FA	First Available
FCA	Fixed Channel Allocation
FCC	Federal Communications Commission
FCH	Frame Control Header
FDMA	Frequency-Division Multiple Access
FEC	Forward Error Correction
FER	Frame Error Rate
FFT	Fast Fourier Transform
FGC	Fractional Guard Channel
FIFO	First-In First-Out
FRU	Flexible ReUse
GC	Guard Channel
GPS	Generalized Processor Sharing
GRP	Greedy Rate Packing
GSM	Global System for Mobile
HARQ	Hybrid ARQ
HOL	Head-Of-Line
i.i.d.	Independent and Identically Distributed
IC	Indifference Curve
IDFT	Inverse DFT
IETF	Internet Engineering Task Force
IFFT	Inverse FFT
IIR	Infinite-Impulse Response
IR	Incremental Redundancy
IS-95	Interim Standard 95
ISI	Inter-Symbol Interference
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
IWFQ	Idealized Wireless Fair Queueing
KKT	Karush–Kuhn–Tucker
LDPC	Low-Density Parity Check
LOS	Line-Of-Sight
LPF	Low-Pass Filter
LWDF	Largest-Weighted-Delay-First
MAC	Medium-Access Control
MAC	Multiple-Access Channel
MAI	Multiple-Access Interference
MCS	Modulation and Coding Scheme

MDP	Markov Decision Process
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
ML	Maximum Likelihood
M-LWDF	Modified Largest-Weighted-Delay-First
M-LWWF	Modified Largest-Weighted-(unfinished)-Work-First
MMSE	Minimum Mean Square Error
MR	Maximal Rate
MRC	Maximal-Ratio Combining
MRS	Marginal Rate of Substitution
MS	Mobile Station
MSIR	Maximum SINR
MSQ	Mean SQuare
MU	Marginal Utility
NAK	Negative AcKnowledgment
NN	Nearest Neighbor
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple-Access
OSI	Open System Interconnection
OSIC	Ordered SIC
PDU	Protocol Data Unit
PF	Proportional Fairness
PFPA	Proportional-Fair Power Allocation
PG	Processing Gain
PPF	Production Possibility Frontier
PSK	Phase-Shift Keying
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RPA	Retransmission Power Adjustment
RT	Real Time
RTG	Receiver/transmitter Transition Gap
SDMA	Space-Division Multiple Access
SDU	Service Data Unit
SE	Spectral Efficiency
SF	Spreading Factor
SIC	Successive Interference Cancellation
SIMO	Single-Input Multiple-Output
SINR	Signal-to-Interference-and-Noise Ratio
SISO	Single-Input Single-Output
SM	Spatial Multiplexing
SNR	Signal-to-Noise Ratio
SSS	Static Service Split
STTD	Space–Time Transmit Diversity
SVD	Singular-Value Decomposition
TCP	Transport Control Protocol

TDMA	Time-Division Multiple-Access
TTG	Transmitter/receiver Transition Gap
UCC	User-Created Contents
UL	UpLink
UMTS	Universal Mobile Telecommunications System
VoD	Video-on-Demand
WCDMA	Wideband CDMA
WFQ	Weighted Fair Queueing
WiMAX	Worldwide Interoperability for Microwave Access
WMAN	Wireless Metropolitan Area Network
WRM	Wireless Resource Management
ZF	Zero-Forcing

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