

**Director of Magazines**Raouf Boutaba, University of Waterloo (Canada)

#### Editor-in-Chief

Osman S. Gebizlioglu, Huawei Tech. Co., Ltd. (USA) Associate Editor-in-Chief

Tarek El-Bawab, Jackson State University (USA)

#### **Senior Technical Editors**

Nim Cheung, ASTRI (China) Nelson Fonseca, State Univ. of Campinas (Brazil) Steve Gorshe, PMC-Sierra, Inc (USA) Sean Moore, Centripetal Networks (USA) Peter T. S. Yum, The Chinese U. Hong Kong (China)

#### **Technical Editors**

Mohammed Atiquzzaman, Univ. of Oklahoma (USA) Guillermo Atkin, Illinois Institute of Technology (USA) Mischa Dohler, King's College London (UK)
Frank Effenberger, Huawei Technologies Co.,Ltd. (USA)
Tarek El-Bawab, Jackson State University (USA) Xiaoming Fu, Univ. of Goettingen (Germany) Stefano Galli, ASSIA, Inc. (USA) Admela Jukan, Tech. Univ. Carolo-Wilhelmina zu Braunschweig (Germany)
Vimal Kumar Khanna, mCalibre Technologies (India)
Yoichi Maeda, Telecommun. Tech. Committee (Japan) Nader F. Mir, San Jose State Univ. (USA) Seshradi Mohan, University of Arkansas (USA) Mohamed Moustafa, Egyptian Russian Univ. (Egypt) Tom Oh, Rochester Institute of Tech. (USA) Glenn Parsons, Ericsson Canada (Canada) Joel Rodrigues, Univ. of Beira Interior (Portugal) Jungwoo Ryoo, The Penn. State Univ.-Altoona (USA) Antonio Sánchez Esguevillas, Telefonica (Spain) Mostafa Hashem Sherif, AT&T (USA) Tom Starr, AT&T (USA)

Ravi Subrahmanyan, InVisage (USA) Danny Tsang, Hong Kong U. of Sci. & Tech. (China) Hsiao-Chun Wu, Louisiana State University (USA) Alexander M. Wyglinski, Worcester Poly. Institute (USA) Jun Zheng, Nat'l. Mobile Commun. Research Lab (China)

**Series Editors** Ad Hoc and Sensor Networks
Edoardo Biagioni, U. of Hawaii, Manoa (USA) Ciprian Dobre, Univ. Politehnica of Bucharest (Romania) Silvia Giordano, Univ. of App. Sci. (Switzerland) Automotive Networking and Applications Wai Chen, Telcordia Technologies, Inc (USA) Luca Delgrossi, Mercedes-Benz R&D N.A. (USA) Timo Kosch, BMW Group (Germany) Tadao Saito, University of Tokyo (Japan) Consumer Communications and Networking
Ali Begen, Cisco (Canada)
Mario Kolberg, University of Sterling (UK)
Madjid Merabti, Liverpool John Moores U. (UK) Design & Implementation
Vijay K. Gurbani, Bell Labs/Alcatel Lucent (USA) alvatore Loreto, Ericsson Research (Finland) Ravi Subrahmanyan, Invisage (USA) Green Communicatons and Computing Networks Song Guo, University of Aizu (Japan) John Thompson, Univ. of Edinburgh (UK) RangaRao V. Prasad, Delft Univ. of Tech. (The Netherlands) Jinsong Wu, Alcatel-Lucent (China) Honggang Zhang, Zhejiang Univ. (China) Integrated Circuits for Communications Charles Chien, CreoNex Systems (USA) Zhiwei Xu, SST Communication Inc. (USA)

Network and Service Management
George Pavlou, U. College London (UK)
Juergen Schoenwaelder, Jacobs University (Germany) Networking Testing and Analytics Ying-Dar Lin, National Chiao Tung University (Taiwan) Erica Johnson, University of New Hampshire (USA) Irena Atov, InCluesive Technologies (USA)

Optical Communications Admela Jukan, Tech. Univ. Braunschweig, Germany (USA) Xiang Lu, Futurewei Technologies, Inc. (USA) Radio Communications

#### Thomas Alexander, Ixia Inc. (USA) Amitabh Mishra, Johns Hopkins Univ. (USA) Columns

Book Reviews
Piotr Cholda, AGH U. of Sci. & Tech. (Poland) History of Communications Steve Weinsten (USA) Regulatory and Policy Issues Scott Marcus, WIK (Germany) Jon M. Peha, Carnegie Mellon U. (USA) Technology Leaders' Forum Steve Weinstein (USA)

Very Large Projects
Ken Young, Telcordia Technologies (USA)

#### **Publications Staff**

Joseph Milizzo, Assistant Publisher Susan Lange, Online Production Manager Jennifer Porcello, Production Specialist Catherine Kemelmacher, Associate Editor





# OMMUNICATIO OMMUNICATIO

SEPTEMBER 2016, vol. 54, no. 9

www.comsoc.org/commag

- 6 THE PRESIDENT'S PAGE
- 8 CONFERENCE CALENDAR
- **GLOBAL COMMUNICATIONS NEWSLETTER**
- 128 ADVERTISERS' INDEX

## COMMUNICATIONS, CACHING, AND COMPUTING FOR CONTENT-CENTRIC MOBILE NETWORKS: PART 2

GUEST EDITORS: MEIXIA TAO, WEI YU, WEI (ANDREW) TAN, AND SUMIT ROY

- 14 GUEST EDITORIAL
- 15 THE THREE PRIMARY COLORS OF MOBILE SYSTEMS Hui Liu, Zhiyong Chen, and Liang Qian
- 22 Caching at the Wireless Edge: Design Aspects, Challenges, and Future Directions Dong Liu, Bingiang Chen, Chenyang Yang, and Andreas F. Molisch
- 29 COMMUNICATIONS, CACHING, AND COMPUTING ORIENTED SMALL CELL NETWORKS WITH INTERFERENCE ALIGNMENT Nan Zhao, Xiaonan Liu, F. Richard Yu, Ming Li, and Victor C. M. Leung
- 36 BIG DATA CACHING FOR NETWORKING: MOVING FROM CLOUD TO EDGE Engin Zeydan, Ejder Bastug, Mehdi Bennis, Manhal Abdel Kader, Ilyas Alper Karatepe, Ahmet Salih Er, and Mérouane Debbah
- 43 IC-MCN: AN ARCHITECTURE FOR AN INFORMATION-CENTRIC MOBILE CONVERGED NETWORK Reza Tourani, Satyajayant Misra, and Travis Mick
- 50 Information-Centric Connectivity

Konstantinos V. Katsaros, Vasilis Sourlas, Ioannis Psaras, Sergi Reñé, and George Pavlou

# **RADIO COMMUNICATIONS:** COMPONENTS, SYSTEMS, AND NETWORKS

SERIES EDITORS: AMITABH MISHRA AND TOM ALEXANDER

- 58 SERIES EDITORIAL
- 59 Massive Machine-Type Communications in 5G: Physical and MAC-Layer Solutions Carsten Bockelmann, Nuno Pratas, Hosein Nikopour, Kelvin Au, Tommy Svensson, Cedomir Stefanovic, Petar Popovski, and Armin Dekorsy
- 66 INDUSTRIAL WIRELESS COMMUNICATIONS OVER THE MILLIMETER WAVE SPECTRUM: OPPORTUNITIES AND CHALLENGES

Michael Cheffena

74 SAFE AND SECURE WIRELESS POWER TRANSFER NETWORKS: CHALLENGES AND OPPORTUNITIES IN RF-BASED SYSTEMS

Qingzhi Liu, Kasım Sinan Yildirim, Przemysław Pawełczak, and Martijn Warnier

80 Full-Duplex Mobile Device: Pushing the Limits

Dani Korpi, Joose Tamminen, Matias Turunen, Timo Huusari, Yang-Seok Choi, Lauri Anttila, Shilpa Talwar, and Mikko Valkama

#### 2016 IEEE Communications Society Elected Officers

Harvey A. Freeman, President
Luigi Fratta, VP-Technical Activities
Guoliang Xue, VP-Conferences
Stefano Bregni, VP-Member Relations
Nelson Fonseca, VP-Publications
Robert S. Fish, VP-Industry and Standards Activities
Sergio Benedetto, Past President

#### Members-at-Large

#### Class of 2016

Sonia Aissa, Hsiao Hwa Chen Nei Kato, Xuemin Shen

#### Class of 2017

Gerhard Fettweis, Araceli Garciá Gómez Steve Gorshe, James Hong

#### Class of 2018

Leonard J. Cimini, Tom Hou Robert Schober, Qian Zhang

#### 2016 IEEE Officers

Barry L. Shoop, President Karen Bartleson, President-Elect Parviz Famouri, Secretary Jerry L. Hudgins, Treasurer Howard E. Michel, Past-President E. Homes Prendergast, Executive Director Celia Desmond, Director, Division III

IEEE COMMUNICATIONS MAGAZINE (ISSN 0163-6804) is published monthly by The Institute of Electrical and Electronics Engineers, Inc. Headquarters address: IEEE, 3 Park Avenue, 17th Floor, New York, NY 10016-5997, USA; tel: +1 (212) 705-8900; http://www.comsoc.org/commag. Responsibility for the contents rests upon authors of signed articles and not the IEEE or its members. Unless otherwise specified, the IEEE neither endorses nor sanctions any positions or actions espoused in IEEE Communications Magazine.

ANNUAL SUBSCRIPTION: \$27 per year print subscription. \$16 per year digital subscription. Non-member print subscription: \$400. Single copy price is \$25.

EDITORIAI. CORRESPONDENCE: Address to: Editor-in-Chief, Osman S. Gebizlioglu, Huawei Technologies, 400 Crossing Blvd., 2nd Floor, Bridgewater, NJ 08807, USA; tel: +1 (908) 541-3591, e-mail: Osman. Gebizlioglu@huawei.com.

COPYRIGHT AND REPRINT PERMISSIONS: Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limits of U.S. Copyright law for private use of patrons: those post-1977 articles that carry a code on the bottom of the first page provided the per copy fee indicated in the code is paid through the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923. For other copying, reprint, or republication permission, write to Director, Publishing Services, at IEEE Headquarters. All rights reserved. Copyright © 2016 by The Institute of Electrical and Electronics Engineers, Inc.

POSTMASTER: Send address changes to IEEE Communications Magazine, IEEE, 445 Hoes Lane, Piscataway, NJ 08855-1331. GST Registration No. 125634188. Printed in USA. Periodicals postage paid at New York, NY and at additional mailing offices. Canadian Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40030962. Return undeliverable Canadian addresses to: Frontier, PO Box 1051, 1031 Helena Street, Fort Eire, ON L2A 6C7.

**SUBSCRIPTIONS:** Orders, address changes — IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA; tel: +1 (732) 981-0060; e-mail: address.change@ieee.org.

ADVERTISING: Advertising is accepted at the discretion of the publisher. Address correspondence to: Advertising Manager, *IEEE Communications Magazine*, 3 Park Avenue, 17th Floor, New York, NY 10016.

SUBMISSIONS: The magazine welcomes tutorial or survey articles that span the breadth of communications. Submissions will normally be approximately 4500 words, with few mathematical formulas, accompanied by up to six figures and/or tables, with up to 10 carefully selected references. Electronic submissions are preferred, and should be sumitted through Manuscript Central: http://mc.manuscriptcentral.com/commag-ieee. Submission instructions can be found at the following: http://www.comsoc.org/commag/paper-submission-guidelines. For further information contact Zoran Zvonar, Associate Editor-in-Chief (zoran.zvonar@mediatek.com). All submissions will be peer reviewed.



#### **NETWORK TESTING AND ANALYTICS**

SERIES EDITORS: YING-DAR LIN, ERICA JOHNSON, AND IRENA ATOV

- 88 SERIES EDITORIAL
- 89 EXPERIMENTAL INVESTIGATION ON A VERTICAL SECTORIZATION SYSTEM WITH ACTIVE ANTENNA Weiliang Xie, Qimei Cui, Fengyi Yang, Qi Bi, and Yifei Yuan
- 98 A LOW-LATENCY TWO-TIER MEASUREMENT AND CONTROL PLATFORM FOR COMMODITY SDN Ming-Hung Chen, Yen-Chen Tien, Yuan-Ting Huang, I-Hsin Chung, and Cheng-Fu Chou
- 105 A LOW-COST NDN TESTBED ON BANANA PI ROUTERS

Benjamin Rainer, Daniel Posch, Andreas Leibetseder, Sebastian Theuermann, and Hermann Hellwagner

### ACCEPTED FROM OPEN CALL

112 MANAGEMENT ARCHITECTURE FOR AGGREGATION OF HETEROGENEOUS SYSTEMS AND SPECTRUM BANDS

Oliver Holland, Adnan Aijaz, Florian Kaltenberger, Fotis Foukalas, Guillaume Vivier, Mateusz Buczkowski, and Slawomir Pietrzyk

120 COMMUNICATIONS CONCERNS FOR REUSED ELECTRIC VEHICLE BATTERIES IN SMART GRIDS
Lluc Canals Casals and Beatriz Amante Garca

#### **CURRENTLY SCHEDULED TOPICS**

TOPIC	Issue <b>D</b> ate	Manuscript Due Date
Fog Computing and <b>N</b> ETWORKING	APRIL 2017	SEPTEMBER 1, 2016
Network Slicing in 5G Systems	May 2017	SEPTEMBER 15, 2016
TRAFFIC MEASUREMENTS FOR CYBER SECURITY	JULY 2017	OCTOBER 1, 2016
Advances in <b>N</b> etworking <b>S</b> oftware	JUNE 2017	NOVEMBER 1, 2016
AGILE RADIO RESOURCE MANAGEMENT TECHNIQUES FOR 5G NEW RADIO	JUNE 2017	NOVEMBER 15, 2016
Education and Training: Telecommunication Standards Education	May 2017	DECEMBER 1, 2016
SOFTWARE-DEFINED VEHICULAR NETWORKS: ARCHITECTURES, ALGORITHMS AND APPLICATIONS	July 2017	DECEMBER 1, 2016
BEHAVIOR RECOGNITION BASED ON WI-FI CHANNEL STATE INFORMATION (CSI)	OCTOBER 2017	FEBRUARY 1, 2017
ADVANCES IN THE NETWORK SERVICES CHAIN	SEPTEMBER 2017	FEBRUARY 1, 2017
EDUCATION & TRAINING: SCHOLARSHIP OF TEACHING AND SUPERVISION	NOVEMBER 2017	May 1, 2017

www.comsoc.org/commag/call-for-papers

### TOPICS PLANNED FOR THE OCTOBER ISSUE

MILITARY COMMUNICATIONS

SDN Use Cases for Service Provider Networks

RECENT ADVANCES IN GREEN INDUSTRIAL NETWORKING

INTEGRATED CIRCUITS FOR COMMUNICATIONS