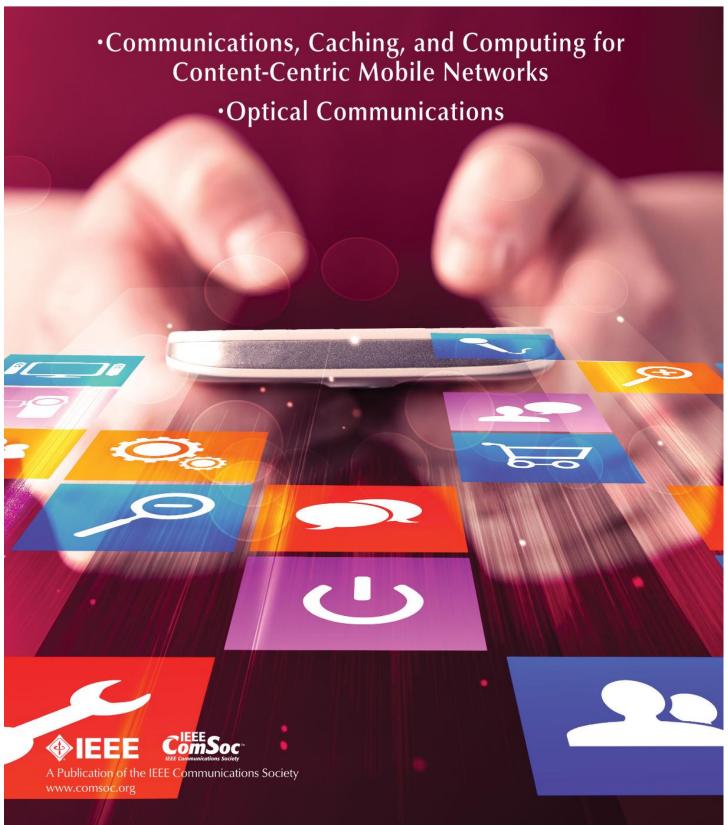
CIEEE August 2016, Vol. 54, No. 8 COMMUNICATIONS MAGAZINE



Director of Magazines

Raouf Boutaba, University of Waterloo (Canada)

Editor-in-Chief

Osman S. Gebizlioglu, Huawei Tech. Co., Ltd. (USA)

Associate Editor-in-Chief

Zoran Zvonar, MediaTek (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

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 Goottingen (Germany)

Stefano Galli, ASSIA, Inc. (USA)

Admela Jukan, Tech, Univ. Carolo-Wilhelmina zu

Braunschweig (Germany)

Admeta 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)

Glenn Parsons, Fricsson 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)
Un Zheng. Nat!, Mobile Commun, Research Lab (China) Jun Zheng, Nat'l. Mobile Commun. Research Lab (China)

Series Editors

Ad Hoc and Sensor Networks
Edoardo Biagioni, U. of Hawaii, Manoa (USA)
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 Communicatons 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)
Salvatore Loreto, Ericsson Research (Finland)
Ravi Subrahmanyan, Invisage (USA)
Green Communications 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

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)

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

Columns

Columns
Book Reviews
Piotr Cholda, AGH U. of Sci. & Tech. (Poland)
History of Communications
Steve Weinsten (USA)
Regulatory and Policy Issues
J. 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

Publications Staff

Joseph Milizzo, Assistant Publisher iusan Lange, Online Production Manager Jennifer Porcello, Production Specialis Catherine Kemelmacher, Associate Editor





OMMUNICATIO OMMUNICATIO

August 2016, vol. 54, no. 8 www.comsoc.org/commag

- 4 THE PRESIDENT'S PAGE
- 8 CONFERENCE REPORT/ICIN 2016
- GLOBAL COMMUNICATIONS NEWSLETTER
- 13 CONFERENCE CALENDAR
- 176 ADVERTISERS' INDEX

COMMUNICATIONS, CACHING, AND COMPUTING FOR CONTENT-CENTRIC MOBILE NETWORKS: PART 1

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

- 14 GUEST EDITORIAL
- 16 WIRELESS CACHING: TECHNICAL MISCONCEPTIONS AND BUSINESS BARRIERS Georgios Paschos, Ejder Baştuğ, Ingmar Land, Giuseppe Caire, and Mérouane Debbah
- 23 CODING FOR CACHING: FUNDAMENTAL LIMITS AND PRACTICAL CHALLENGES Mohammad Ali Maddah-Ali and Urs Niesen
- 30 PHY-CACHING IN 5G WIRELESS NETWORKS: DESIGN AND ANALYSIS Wei Han, An Liu, and Vincent K. N. Lau
- 37 GAME THEORETIC APPROACHES FOR WIRELESS PROACTIVE CACHING Zhiwen Hu, Zijie Zheng, Tao Wang, Lingyang Song, and Xiaoming Li
- HARNESSING CLOUD AND EDGE SYNERGIES: TOWARD AN INFORMATION THEORY OF FOG RADIO **ACCESS NETWORKS**

Ravi Tandon and Osvaldo Simeone

- 52 THE ROLE OF CLOUD COMPUTING IN CONTENT-CENTRIC MOBILE NETWORKING Jianhua Tang and Tony Q. S. Quek
- 60 EXPLORING SYNERGY BETWEEN COMMUNICATIONS, CACHING, AND COMPUTING IN 5G-GRADE **DEPLOYMENTS**

Sergey Andreev, Olga Galinina, Alexander Pyattaev, Jiri Hosek, Pavel Masek, Halim Yanikomeroglu, and Yevgeni Koucheryavy

ENHANCEMENT FOR CONTENT DELIVERY WITH PROXIMITY COMMUNICATIONS IN CACHING **ENABLED WIRELESS NETWORKS: ARCHITECTURE AND CHALLENGES**

Min Sheng, Chao Xu, Junyu Liu, Jiongjiong Song, Xiao Ma, and Jiandong Li

77 MOBILITY-AWARE CACHING FOR CONTENT-CENTRIC WIRELESS NETWORKS: MODELING AND METHODOLOGY

Rui Wang, Xi Peng, Jun Zhang, and Khaled B. Letaief

- SOCIALLY AWARE INTEGRATED CENTRALIZED INFRASTRUCTURE AND OPPORTUNISTIC NETWORKING: A POWERFUL CONTENT DISSEMINATION CATALYST Jie Hu, Lie-Liang Yang, Kun Yang, and Lajos Hanzo
- 92 NMRTS: CONTENT NAME-BASED MOBILE REAL-TIME STREAMING Kazuhisa Matsuzono and Hitoshi Asaeda
- 100 SAVING: Socially Aware Vehicular Information-Centric Networking Junaid Ahmed Khan and Yacine Ghamri-Doudane

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. James 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 endorse or spartings any positions or actions exponsed in IEEE. 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.

EDITORIAL 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 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. 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-submis-sion-guidelines. For further information contact Zoran Zvonar, Associate Editor-in-Chief (zoran.zvonar@mediatek.com). All submissions will be peer reviewed.



OPTICAL COMMUNICATIONS NETWORKS

SERIES EDITORS: ADMELA JUKAN AND XIANG LIU

- 108 SERIES EDITORIAL
- 110 PHYSICAL-LAYER SECURITY IN EVOLVING OPTICAL NETWORKS Nina Skorin-Kapov, Marija Furdek, Szilard Zsigmond, and Lena Wosinska
- 118 C-RoFN: Multi-Stratum Resources Optimization for Cloud-Based Radio over Optical FIBER NETWORKS

Hui Yang, Jie Zhang, Yuefeng Ji, and Young Lee

126 CONTROL PLANE SOLUTIONS FOR SLICEABLE BANDWIDTH TRANSCEIVER CONFIGURATION IN FLEXI-GRID OPTICAL NETWORKS

Ricardo Martínez, Filippo Cugini, Ramon Casellas, Francesco Paolucci, Ricard Vilalta, Piero Castoldi, and Raul Muñoz

136 A CONTROL PLANE ARCHITECTURE FOR MULTI-DOMAIN ELASTIC OPTICAL NETWORKS: THE VIEW OF THE IDEALIST PROJECT

Ramon Casellas, Oscar González, Francesco Paolucci, Roberto Morro, Víctor López, Daniel King, Ricardo Martínez, Filippo Cugini, Ral Muñoz, Adrian Farrel, Ricard Vilalta, Juan-Pedro Fernández-Palacios

144 COST ASSESSMENT OF FTTDP NETWORKS WITH G.FAST

Juan Rendon Schneir and Yupeng Xiong

153 Low-Cost Hybrid ROADM Architectures for Scalable C/DWDM Metro Networks Md. Nooruzzaman and Elbiaze Halim

ACCEPTED FROM OPEN CALL

- 162 Physical Layer Security Issues in Interference-Alignment-Based Wireless Networks Nan Zhao, F. Richard Yu, Ming Li, Qiao Yan, and Victor C. M. Leung
- 169 FRONTHAUL CELL OUTAGE COMPENSATION FOR 5G NETWORKS Mohamed Selim, Ahmed E. Kamal, Khaled Elsayed, Heba M. Abdel-Atty, and Mohammed Alnuem

CURRENTLY SCHEDULED TOPICS

ТОРІС	ISSUE DATE	Manuscript Due Date
FOG COMPUTING AND NETWORKING	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
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
BEHAVIOR RECOGNITION BASED ON WI-FI CHANNEL STATE INFORMATION	OCTOBER 2017	FEBRUARY 1, 2017
EDUCATION AND TRAINING: SCHOLARSHIP OF TEACHING AND SUPERVISION	NOVEMBER 2017	MAY 1, 2017

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

TOPICS PLANNED FOR THE SEPTEMBER ISSUE

COMMUNICATIONS, CACHING, AND COMPUTING FOR CONTENT-CENTRIC MOBILE NETWORKS RADIO COMMUNICATIONS

NETWORK TESTING AND ANALYTICS

FROM THE OPEN CALL QUEUE

COMMUNICATIONS CONCERNS FOR REUSED ELECTRIC VEHICLE BATTERIES IN SMART GRIDS TOWARD THE DEVELOPMENT OF A TECHNO-SOCIAL SMART GRID GREEN DATAPATH: ENERGY-AWARE ROUTING ARCHITECTURE FOR TCAM-BASED SDN NETWORKS