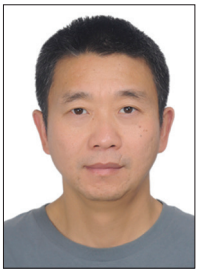
Content-Centric Collaborative Edge Caching in 5G Mobile Internet




Xiaofei Wang Tarik Taleb Zhu Han Shugong Xu Victor C. M. Leung

In recent years, with the rapid development of information and communication technologies (ICTs), mobile network operators are increasingly suffering from the traffic explosion problem. And this problem remains to be tackled in the upcoming fifth generation (5G) networks. However, due to the limited bandwidth, the need to save energy, and the fact that advancements in transmission techniques are approaching the Shannon limit with diminishing returns, it is clear that these advancements need to be complemented by improvements in the network, transport, and application layers to provide sustainable solutions toward richer network capacity.

The purpose of this Feature Topic is to look for expositions on novel functionalities and technologies in various wireless and mobile network caching equipment, with respect to caching algorithms, caching implementations, system integration, cache modeling, optimization, and so on. Through the Call for Papers and rigorous peer review, 15 articles have been selected from a total of 47 submissions for inclusion, addressing different aspects of the topic as follows.

Edge Caching Policy and Optimization

The authors of "Hierarchical Caching for Statistical QoS Guaranteed Multimedia Transmissions over 5G Edge-Computing Mobile Wireless Networks" propose three hierarchical edge caching mechanisms to efficiently support multimedia services over 5G wireless networks. The caching mechanisms, which include random, proactive, and game-theory-based hierarchical caching mechanisms, remedy the difficulties of integrating in-network caching and edge computing for multimedia transmissions over 5G wireless networks.

The article "Edge-CoCaCo: Toward Joint Optimization of Computation, Caching, and Communication on the Edge Cloud" introduces a new concept of task caching, different from the existing studies, which use content and computation offloading to reduce the delay of tasks. For the tasks that could be cached on the edge cloud, the proposed Edge-CoCaCo achieves low delay of processing by joint optimization of communication, caching, and computing.

Another two articles that exploit machine learning or big data for further optimizing the caching policy are given below. Utilizing the fact that base stations and user equipment are becoming more intelligent and richer in communication and computing capabilities, the article "Learn to Cache: Machine Learning for Network Edge Caching in the Big Data Era" explores the big data analytics technique, by which content popularity estimation and proactive caching strategy design can be obtained to advance the edge caching capability. Aiming to cache popular application services at edge equipment, the authors of "Temporal-Spatial Mobile Application Usage Understanding and Popularity Prediction for Edge Caching" propose to collect mobile big data from network interfaces for data mining. The analysis results on the traffic consumption and app usage pattern under different base stations can further be used in designing edge caching schemes.

D2D-Aided Edge Caching

The articles "Collaborative Caching and Matching for D2D Content Sharing" and "Caching-Aided Collaborative D2D Operation for Predictive Data Dissemination in Industrial IoT" both explore the assistance of device-to-device (D2D) communications. However, their application scenarios are a bit different.The former article considers distributed caching with the aid of D2D in the mobile wireless communication case. The authors propose a distributed cache management scheme, which involves the caching decision and model updating, and a best effort distributed algorithm framework. Moreover, a content sharing mode selection model is designed to obtain the optimal matching for communication pairs.

The authors of the latter article propose to engage moving industrial machines as a D2D caching helper in industrial automation, where massive contents produced by moving Internet of Things (IoT) machines should be delivered to the edge network infrastructure and then forwarded to remote human operators by reliable and high-rate radio links. For maintaining the reliability of data connections, alternative contents dissemination modes coupled with predictive mode selection strategies based on the anticipated radio link conditions are presented, and then their effectiveness is demonstrated by evaluation.

Incentive Scheme Design in Edge Caching

For mobile crowdsensing systems (MCSs), the authors of "Data Quality Guarantee for Credible Caching Device Selection in Mobile Crowdsensing Systems" present a comprehensive study on the data quality problem in cache-enabled MCSs. Specifically, without the quality-aware behavior evaluation of temporally recruited mobile users, the dishonest behaviors of self-interested mobile users who might induce severe data cannot be identified. Therefore, a quality-driven incentive method is developed to encourage mobile users to provide high-quality data actively, and quality-aware behavior evaluation is achieved for credible caching device selection.

In the next article, "REPSYS: A Robust and Distributed Incentive Scheme for In-Network Caching and Dissemination in Vehicular Delay-Tolerant Networks," an incentive scheme for in-network caching and dissemination in vehicular delay-tolerant networks (REPSYS) is proposed. This incentive scheme is distributed. The scheme not only takes into account first- and second-hand information, but is also resilient against false accusations and praise. The performance evaluation demonstrates that such a scheme can classify vehicles in most cases correctly.

In the last article in this section, "On the Incentive Mechanisms for Commercial Edge Caching in 5G Wireless Networks,"the authors focus on the design of incentive mechanisms for commercial edge caching in 5G cellular networks. For the purpose of coordinating the welfare of the edge device providers (EDPs) and content providers (CPs), due to the fact that EDPs and CPs both want to achieve their highest benefit by squeezing profits from the others, game theoretical approaches are introduced to balance the conflict.

Caching Architecture and Security

Six articles are included in this section. The first four articles are concerned with caching architecture, and the last two particularly focus on security issues.

The article "Cooperative Content Caching in 5G Networks with Mobile Edge Computing" tackles the neglected fact that storage and computing resources are treated separately, and the mobility characteristics of both the content caching nodes and end users are not considered in the existing literature. Accordingly, the authors propose a new cooperative edge caching architecture for 5G networks, which synthetically takes into account the caching and computing resources optimization, and mobility awareness of base stations and smart vehicles.

To fuse edge-centric computing (ECC) and content-centric networking (CCN) together and provide manageable and flexible services, the difficulty lies in their different architectures and protocols. "ECCN: Orchestration of Edge-Centric Computing and Content-Centric Networking in 5G Radio Access Networks" presents ECCN, which is an orchestrating scheme that integrates ECC and CCN into a hierarchical structure with software defined networking.

Instead of focusing on theoretical edge caching policies, the authors of "Collaborative Edge Caching through Service Function Chaining: Architecture and Challenges" study the practical implementation issues of edge caching. They propose that the mobile edge applications in the architecture of edge caching can be provided by integrating the service function chaining with the aid of edge computing techniques and virtualized resources. Also, a proof-of-concept architecture is further verified by experiments.

A social trust scheme that enhances the security of mobile social networks is presented in the article "Secure Social Networks in 5G Systems with Mobile Edge Computing, Caching and Device-to-Device (D2D) Communications." In this scheme, the authors use uncertain reasoning to derive trust values due to the uncertainty in trust evaluation.

To jointly manage the radio resources and the cache at the edge of networks, in "Resource Allocation in NOMA-Based Fog Radio Access Networks," the authors propose an architecture of a non-orthogonal multiple access (NOMA)-based fog radio access network that can meet the heterogeneous requirements in 5G systems.

The authors of "Security in Mobile Edge Caching with Reinforcement Learning" apply reinforcement-learning-based security solutions to provide secure offloading to the edge nodes against jamming attacks. Lightweight authentication and secure collaborative caching schemes are also presented for further protecting data privacy.

As the conclusion of this editorial, we would like to express our sincere appreciation to all the authors for their submitted articles and the reviewers for their contributions to this Feature Topic. We hope the efforts of all contributors can provide various views of the state of the art on this Feature Topic. Last but not least, on account of his valuable guidance and support, our heartfelt thanks are given here to the Editor-in-Chief of *IEEE Wireless Communications*.

Biographies

Xiaofei Wang is a professor in the Tianjin Key Laboratory of Advanced Networking, School of Computer Science and Technology, Tianjin University, China. He is the recipient of the Thousand Talents Plan (Youth) and Peiyang Scholar of Tianjin University. His current research interests are social-aware multimedia service in cloud computing, cooperative backhaul caching, and traffic offloading in mobile content-centric networks. He has published more than 80 papers and has served as lead GE for several magazines, transactions, and journals. Also, he won the Fred W. Ellersick Prize of the IEEE Communications Society in 2017.

Tarik Taleb is a professor at the School of Electrical Engineering, Aalto University, Finland. His research interests lie in the field of architectural enhancements to mobile core networks (particularly 3GPP's), mobile cloud networking, network functions virtualization, and software defined networking. He has served as an Editor-in-Chief, Editorial Board member, and General Chair for various journals including IEEE transactions.

Zhu Han [F'14] is a John and Rebecca Moores Professor in the Electrical and Computer Engineering Department as well as in the Computer Science Department at the University of Houston, Texas. His research interests include wireless resource allocation and management, wireless communications and networking, game theory, big data analysis, security, and smart grid. He is currently an IEEE Communications Society Distinguished Lecturer. He is a highly cited researcher in 2017 according to Web of Science.

Shugong Xu [F] is a professor at Shanghai University and head of the Shanghai Institute for Advanced Communication and Data Science (SICS). In his 20+ years career in research (over 15 years in industrial research labs), he has had over 40 issued U.S./WO/CN patents and published more than 100 peer-reviewed research papers. His work was one of the major triggers of the research and standardization of IEEE 802.11S. He was awarded the National Innovation Leadership Talent from the China government in 2013 and was named an IEEE Fellow for "contributions to the improvement of wireless network efficiency" in 2015. He also won the 2017 Award for Advances in Communication from IEEE Communications Society. He received his B.S. degree from Wuhan University, and his M.E. and Ph.D. degrees from Huazhong University of Science and Technology. His current research interests include wireless communication systems and machine learning.

Victor C. M. Leung [F'03] is a professor of electrical and computer engineering and holder of the TELUS Mobility Research Chair at the University of British Columbia, Vancouver, Canada. He has co-authored more than 1100 technical papers in the areas of wireless networks and mobile systems. He was the recipient of the 1977 APEBC Gold Medal, a 2011 UBC Killam Research Prize, an IEEE Vancouver Section Centennial Award, the 2017 Canadian Award for Telecommunications Research, and the 2018 IEEE ComSoc TGCC Distinguished Technical Achievement Recognition Award. He co-authored papers that won the 2017 IEEE Communications Society Fred W. Ellersick Prize, the 2017 *IEEE Systems Journal* Best Paper Award, and the 2018 IEEE ComSoc CSIM Best Journal Paper Award. He is a Fellow of the Royal Society of Canada, the Canadian Academy of Engineering and the Engineering Institute of Canada.