Federated Optimizations and Networked Edge Intelligence

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Recently, with the maturity of edge-cloud computing and the large amount of data generated in the edge, we have witnessed an increasing number of applications conducting collaborative learning and data analytics in networked edge systems. On the other end of the spectrum, there are also fast-growing concerns on privacy on using the data in the edge, which belong to diverse owners. Federated learning (FL) and federated analytics (FA), coined together as federated optimizations by Google, are new distributed computing techniques to address such a mismatch. In federated optimization, raw data are kept local and only the focused updates (weights or data insights) generated from local analytics are sent to a cloud server for result aggregation.

The advancement of federated optimizations has created promising opportunities to enable increasingly complex networked systems, to become more intelligent and autonomous in network management with privacy protection. Despite the potential and opportunities that federated optimizations bring about to facilitate network management in privacy-demanding environments, there remain many challenges. This Special Issue (SI) aims to look into the fundamental challenges and opportunities that intersect between federated optimizations and networked systems. In response to the Call for Papers, we received a total of 40 high-quality submission across the world. After a rigorous review process, 11 outstanding articles have been selected for this SI, covering the following four major areas:

1. Applying federated optimization to support diverse applications
2. New aspects in federated optimization
3. Performance improvement in federated optimization
4. New supporting technologies for federated optimization

Area 1: Applying Federated Optimization to Support Diverse Applications

In the article "Collaboration-Enabled Intelligent Internet Architecture: Opportunities and Challenges," the authors propose the collaboration-enabled intelligent Internet architecture, which can leverage intelligence to facilitate the evolution of Internet architecture in more complex scenarios. The authors first discuss the inherent opportunities and challenges of enabling the Internet architecture to be intelligent through collaboration. The authors then present a newly proposed collaboration-enabled intelligent Internet architecture, which consists of heterogeneous hardware infrastructure and collaboration-oriented software service platform. Finally, the authors take multi-classification malicious traffic detection as a case study and demonstrate the advantages of enabling Internet architecture to be intelligent through collaboration.

In the article "Satellite MEC with Federated Learning: Architectures, Technologies and Challenges," the authors study federated learning in the context of satellite networks, where the raw data of edge users vested in different owners cannot be shared due to data privacy requirements. Federated learning (FL) is an excellent fit and the authors construct a FL-based satellite MEC architecture. The authors introduce its key techniques in the aspect of resource management and multimodal data fusion. Furthermore, the authors study the data privacy and security protection on the FL-aided satellite MEC relying on a blockchain framework and portray the challenges of FL-aided satellite MEC systems.

In the article "Providing Location Information at Edge Networks: A Federated Learning-Based Approach," the authors argue that the location information of edge devices is essential to support many scenarios like smart home, smart city and smart health. Yet location information leakage limits its application. The authors propose to leverage federated learning (FL) to alleviate these concerns. Specifically, the authors illustrate an FL-based localization system and point out its advantages. On practical implementation of this system, the authors discuss the important field-specific issues associated with the design of the related system-level solutions, which are further demonstrated over a real-word database.

In the article "A Cross-Domain Federated Learning Framework for Wireless Human Sensing," the authors study the problem of leveraging federated learning for wireless human sensing, which require a large amount of training data to achieve good performance. In addition, there are issues, such as a wireless signal is easily interrupted by the environment and the data across all participants is non-IID; all these lead to a performance decrease. The authors propose a cross-domain federated learning framework (CDFL) to address the lack of labeled wireless data. A transfer learning approach is proposed to simulate wireless data and the distribution mismatch problem is solved by domain adaptation. The authors demonstrate the effectiveness of the proposed framework using a case study of ultrasonic signal-based gesture recognition.

Area 2: New Aspects in Federated Optimization

In the article "Federated Unlearning: Guarantee the Right of Clients to Forget," the authors investigate the issues on "The Right to be Forgotten," i.e., a data owner has the right to revoke their data from an entity storing it. The authors study this issue in the context of federated learning, a process the authors name it federated unlearning. The authors define the problem of efficient federated unlearning and identify three common types of federated unlearning requests namely class unlearning, client unlearning and sample unlearning. The authors propose a general pipeline for federated unlearning and revisit the nature how the training data affects the final FL model performance, and thereby empower the proposed framework with the reverse stochastic gradient ascent (SGA) and elastic weight consolidation (EWC).

In the article "Asynchronous Semi-Supervised Federated Learning with Provable Convergence in Edge Computing," the authors study semi-supervised learning in federated learning scenarios to address the lack of labels. The authors observe performance suffers from slow training and non-convergence in real network environments and propose Federated Incremental Learning (FedIL) as a semi-supervised federated learning (SSFL) framework to overcome the limitations of SSFL. FedIL introduces a group-based asynchronous training algorithm with provable convergence, which accelerates model training by allowing more clients to participate simultaneously.

Area 3: Performance Improvement in Federated Optimization

In the article "Multi-user QoE Enhancement: Federated Multi-agent reinforcement Learning for Cooperative Edge Intelligence," the authors study the problem on cooperation of network edges and quantification of the multi-user QoE. The authors consider federated multi-agent reinforcement learning and propose a cooperative edge intelligence architecture supporting computation offloading with vertical-horizontal cooperation. We model a comprehensive system cost to quantify the multi-user QoE and formulate the optimization problem as minimizing the expected long-term system cost.

In the article "Quality-Oriented Federated Learning on the Fly," the authors argue that it is important to recognize that the model contributions from local training on different edge devices are substantially different and existing studies fail to capture the effect of highly variable data and heterogeneous resources available on participating edge devices. The authors propose a new aggregation mechanism that uses deep reinforcement learning to dynamically evaluate the quality of model updates, with accommodations for data and device heterogeneity as the training process progresses. By dynamically mapping the quality of local models to their importance during model aggregation, the global training process is able to converge towards the direction of better effectiveness and generalization.

Area 4: New Supporting Technologies for Federated Optimization

In the article "CON: A Computation-Oriented Network for Efficient Edge Intelligence," the authors observe edge intelligence poses the design requirements on efficient networking technology including One Request Multiple Reply in a time Interval (ORMRI), computation aggregation, and chained computation, which have not been well addressed in existing networking studies. To satisfy those requirements, the authors design a Computation-Oriented Network (CON) to enable the efficient discovery, task allocation, and collaborative computations for edge devices. In CON, model and datasets are afforded with the names for direct resource discovery, and a hybrid computation-oriented routing (HCOR) mechanism has been proposed, which combines proactive and reactive routing approaches.

In the article "Differentially Private Federated Learning in Edge Networks: The Perspective of Noise Reduction," the authors address the privacy leakage when exchanging messages between edge devices and the edge server by differential privacy where well-designed noise is added to target data/models. The authors note that the added noise will deteriorate learning performance, and it is challenging to get a satisfactory tradeoff between privacy protection and learning performance. This article gives the first systematic study on the framework of differentially private FL in edge networks from the perspective of noise reduction. Three promising research directions for noise reduction are summarized based on the intrinsic factors influencing the added noise scale, including privacy amplification, model sparsification and sensitivity reduction.

In the article "Accountable and Verifiable Secure Aggregation for Federated Learning in IoT Networks," the authors study federated learning with secure aggregation. The author observe that existing solutions employ an aggregation server to compute a multiparty sum of model parameter updates of each participant using secure multiparty computation (SMC). However, this solution is based on the semi-honest assumption, which is vulnerable to malicious clients. The authors propose an accountable and verifiable secure aggregation. Specifically, the authors employ a SMC protocol based on homomorphic proxy re-authenticators and homomorphic proxy re-encryption to execute secure aggregation, while integrating the blockchain to realize the function of penalty for malicious behavior. This framework can guarantee the verifiability of data provenance and is accountable for malicious client.

In closing, the Guest Editors would like to thank all the authors who submitted their original research work to this SI, and all the reviewers who provided timely and constructive review comments. In addition, we are grateful to Dr. Chonggang Wang, Editor-in-Chief, for his continuous support and guidance, as well as the IEEE Network staff for their invaluable support during the course of the preparation of this SI.

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