Guest Editorial

Special Issue on Data Analytics and Machine Learning for Network and Service Management - Part II

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Guest Editorial: Special Issue on Data Analytics and Machine Learning for Network and Service Management—Part II

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I. Introduction

NETWORK and Service analytics can harness the immense stream of operational data from clouds, to services, to social and communication networks. In the era of big data and connected devices of all varieties, analytics and machine learning have found ways to improve reliability, configuration, performance, fault and security management. In particular, we see a growing trend towards using machine learning, artificial intelligence and data analytics to improve operations and management of information technology services, systems and networks.

Research is therefore needed to understand and improve the potential and suitability of data analytics and machine learning in the context of services, systems and network management. This will provide deeper understanding and better decision making based on largely collected and available operational and service data. It will also present opportunities for improving machine learning and data analytics algorithms and methods on aspects such as reliability, dependability and scalability, as well as demonstrate the benefits of these methods in management and control systems. Moreover, there is an opportunity to define novel platforms that can harness the vast operational data and advanced data analysis algorithms to drive management decisions in networks, data centers, and clouds.

This special issue of IEEE Transactions on Network and Service Management presents novel research tackling the above challenges. It is the fourth special issue in this area to appear in this series, after issues published in [1], [2], [3]. The collection of works we present illustrates recent trends, novel solutions and approaches to leverage Data analytics and Machine Learning in Network and Service management, as well as to extract insights from data that can guide system operators and network managers in their daily activities.

The special issues consists of two parts. In Part II, presented here, we have accepted 23 papers out of 84 papers submitted to the open call for novel contributions addressing the underlying challenges of *Data Analytics and Machine Learning for Network and Service management*. Part I was published in the previous issue (December 2020 issue [4]).

II. Special Issue Overview

The special issue papers span three central areas of *Data Analytics and Machine Learning for Management*: (i) Data Analytics and Machine Learning for Network Management, (ii) Data Analytics and Machine Learning for Service Management, and (iii) Advanced Security Management based on Data Analytics and Machine Learning.

A. Data Analytics and Machine Learning for Network Management

Ten papers in this special issue focus on data analytics and machine learning for management of networks.

In “Tensor-Based Recurrent Neural Network and Multi-Modal Prediction With Its Applications in Traffic Network Management,” Wu *et al.* [item 1) in the Appendix] presents a tensor-based recurrent neural network approach to predict traffic flows. Empirical evaluations on the metro traffic flow dataset demonstrate that the proposed approach can improve the traffic flow prediction accuracy compared to the traditional approaches on the same dataset.

In “Detection and Characterization of Network Anomalies in Large-Scale RTT Time Series,” Hou *et al.* [item 2) in the Appendix] propose an unsupervised learning based approach for the detection and characterization of general network anomalies. Then, they analyze the relations between links with state changes and localize the entities that most likely cause the corresponding event.

In “Adaptive Network Latency Prediction From Noisy Measurements,” Tripathi and Rajawat [item 3) in the

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Appendix] explore the estimation and prediction of network latencies from a sequence of noisy and incomplete latency matrices collected over time. Theoretical and empirical evaluations demonstrate the viability of the proposed approach as a network monitoring tool.

In "Host Behavior in Computer Network: One-Year Study," Jirsik and Velan [item 4) in the Appendix] present their study of the host behaviors on a one-year-long real-world network dataset. They inspect the availability of the data for host profiling, identify the temporal patterns in host behavior, introduce a method for stable labeling of the hosts, and assess the variability of the host characteristics.

In "Online Anomaly Detection Leveraging Stream-Based Clustering and Real-Time Telemetry," Putina and Rossi [item 5) in the Appendix] benchmark seven unsupervised learning algorithms to the streaming flow of control and data-plane telemetry data with the purpose of real-time anomaly detection. Five of these algorithms are designed for evolving data streams whereas two are not. Their results show that DenStream, one of the five unsupervised learning algorithms designed for evolving data, outperforms the other six.

In "An LSTM Framework for Software-Defined Measurement," Lazaris and Prasanna [item 6) in the Appendix] present a deep learning based framework for scalable software-defined measurement for several network management tasks from traffic engineering to load balancing. Empirical evaluations using real network traces show that the proposed approach outperforms the baselines employed.

In "Intelligent Routing Based on Reinforcement Learning for Software-Defined Networking," Casas-Velasco *et al.* [item 7) in the Appendix] introduce a machine learning approach for routing in Software-Defined Networking (SDN), namely Reinforcement Learning and Software-Defined Networking Intelligent Routing. They capitalize on the interaction with the environment using reinforcement learning, and the global view and control of the network provided by Software Defined Networking, to compute and install optimal routes in the forwarding devices, in advance.

In "Burst Traffic Scheduling for Hybrid E/O Switching DCN: An Error Feedback Spiking Neural Network Approach," Yu *et al.* [item 8) in the Appendix] presents a feedback-based spiking neural network approach for high accuracy burst traffic prediction. They then design a prediction-assisted scheduling algorithm to manage the worst-case burst traffic. The simulation results show that the approach can efficiently integrate a spiking neural network into the traffic scheduling scheme.

In "STAD: Spatio-Temporal Anomaly Detection Mechanism for Mobile Network Management", Dridi *et al.* [item 9) in the Appendix] explore a dynamic on-line data mining technique to detect network anomalies allowing operators to pro-actively monitor and control a variety of real-world phenomena. Based on real cellular communication traces, they propose STAD, an automated framework that aims to ensure spatio-temporal detection of outliers using a combination of machine learning techniques.

In "Characterization and Prediction of Mobile-App Traffic using Markov Modeling", Aceto *et al.* [item 10) in the Appendix] seek to analyze publicly available mobile-app traffic, namely MIRAGE-2019, using Markov Chains and Hidden Markov Model learning algorithms. They discuss and empirically evaluate the suitability of the learning algorithms for different network management tasks.

B. Data Analytics and Machine Learning for Service Management

Six papers in this special issue focus on data analytics and machine learning for management of services.

In "QoS Time Series Modeling and Forecasting for Web Services: A Comprehensive Survey", Syu and Wang [item 11) in the Appendix] review and investigate the current Web services quality of service time series modeling and forecasting research in the literature. They classify and discuss the current studies in terms of the four components that are identified and provide overall guidelines for the researchers in this area.

In "CEDULE+: Resource Management for Burstable Cloud Instances Using Predictive Analytics", Pinciroli *et al.* [item 12) in the Appendix] present CEDULE+ predictive data analytics to optimize the management of burstable instances in cloud workload variations. They evaluate the proposed system on Amazon EC2 and assess its efficiency and high accuracy through real-case scenarios.

In "Machine Learning-based Scaling Management for Kubernetes Edge Clusters", Toka *et al.* [item 13) in the Appendix] introduce a Kubernetes scaling engine that enables the automatic scaling decision parameters to be set dynamically for managing the variability of incoming requests. This engine uses various machine learning forecast methods that compete with each other via a short-term evaluation loop to suit to the request dynamics.

In "Profit Maximization of Online Service Function Chain Orchestration in an Inter-Datacenter Elastic Optical Network," Yu *et al.* [item 14) in the Appendix] explore online service function chain provisioning in inter-datacenter elastic optical networks. They design and evaluate time-efficient orchestration algorithms for online service function chain requests.

In "Deep-FDA: Using Functional Data Analysis and Neural Networks to Characterize Network Services Time Series," Perdices *et al.* [item 15) in the Appendix] introduce a deep learning based approach for network service modeling using functional data analysis. They evaluate and demonstrate the applicability of the proposes approach on synthetic and real-world data, and compare to other state-of-the-art alternatives.

In "Mosaic: Advancing User Quality of Experience in 360-Degree Video Streaming With Machine Learning," Park *et al.* [item 16) in the Appendix] present a comprehensive approach called Mosaic that combines a neural network based viewport prediction with a rate control mechanism for streaming 360-degree panoramic videos. They provide a comprehensive performance evaluation of Mosaic along with five other streaming techniques.

C. Advanced Security Management Based on Data Analytics and Machine Learning

Seven papers in this special issue focus on Advanced Security Management based on Data Analytics and Machine Learning.

In "Detecting Anomalies at a TLD Name Server Based on DNS Traffic Predictions," Madariaga *et al.* [item 17) in the Appendix] propose a near real-time anomaly detection based on prediction approach to detect anomalies in DNS traffic. They show that the proposed approach improves upon the current state-of-the-art anomaly detection in authoritative TLD name servers.

In "Hierarchical Anomaly-Based Detection of Distributed DNS Attacks on Enterprise Networks," Lyu *et al.* [item 18) in the Appendix] seek to detect distributed DNS attacks using a hierarchical graph structure combined with machine learning. The evaluations are performed on a month worth of DNS data from the two enterprises and the results are compared against blacklists and firewall logs. Results show the ability of the system in detecting distributed attacks while maintaining a reasonable real-time performance.

In "Uncovering Lateral Movement Using Authentication Logs," Bian *et al.* [item 19) in the Appendix] employ a machine learning based approach to detect hosts in a network that are targets of an advanced persistent threat attack. They evaluate several machine learning classifiers to detect susceptible hosts in the Los Alamos National Lab dataset.

In "Adaptive Protection of Scientific Backbone Networks Using Machine Learning," Mogyorósi *et al.* [item 20) in the Appendix] utilize a machine learning scheme to achieve a backbone protection scheme that periodically re-allocates the unused capacity to meet the service availability requirements. They demonstrate and evaluate their scheme on the real traffic from Energy Sciences Network (ESnet), which is a high-speed, international scientific backbone network.

In "WIDS: An Anomaly Based Intrusion Detection System for Wi-Fi (IEEE 802.11) Protocol," Satam and Hariri [item 21) in the Appendix] introduce a wireless intrusion detection system using an anomaly behavior analysis approach. They represent the normal behavior using n-grams and use machine learning models to classify Wi-Fi traffic flows. The proposed system is evaluated on the University of Arizona and AWID datasets.

In "Comparative Assessment of Process Mining for Supporting IoT Predictive Security," Hemmer *et al.* [item 22) in the Appendix] present the exploitability and performance of a process mining approach for detecting misbehaviors in Internet-of-Things systems. They describe a proof-of-concept prototype security management system, and evaluate it on different industrial datasets.

In "Gradient Boosting Feature Selection With Machine Learning Classifiers for Intrusion Detection on Power Grids," Upadhyay *et al.* [item 23) in the Appendix] present an integrated framework for an intrusion detection system for smart grids which combines feature engineering with machine learning classifiers. They implement and evaluate various decision tree based machine learning techniques after obtaining the most promising features of the power grid dataset.

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Appendix
Related Works

1) Q. Wu *et al.*, "Tensor-based recurrent neural network and multi-modal prediction with its applications in traffic network management," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 780–792, Mar. 2021.
2) B. Hou, C. Hou, T. Zhou, Z. Cai, and F. Liu, "Detection and characterization of network anomalies in large-scale RTT time series," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 793–806, Mar. 2021.
3) R. Tripathi and K. Rajawat, "Adaptive network latency prediction from noisy measurements," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 807–821, Mar. 2021.
4) T. Jirsik and P. Velan, "Host behavior in computer network: One-year study," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 822–838, Mar. 2021.
5) A. Putina and D. Rossi, "Online anomaly detection leveraging stream-based clustering and real-time telemetry," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 839–854, Mar. 2021.
6) A. Lazaris and V. K. Prasanna, "An LSTM framework for software-defined measurement," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 855–869, Mar. 2021.
7) D. M. Casas-Velasco, O. M. C. Rendon, and N. L. S. da Fonseca, "Intelligent routing based on reinforcement learning for software-defined networking," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 870–881, Mar. 2021.
8) A. Yu, H. Yang, K. K. Nguyen, J. Zhang, and M. Cheriet, "Burst traffic scheduling for hybrid E/O switching DCN: An error feedback spiking neural network approach," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 882–893, Mar. 2021.
9) A. Dridi, C. Boucetta, S. E. Hammami, H. Afifi, and H. Moungla, "STAD: Spatio-temporal anomaly detection mechanism for mobile network management," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 894–906, Mar. 2021.
10) G. Aceto, G. Bovenzi, D. Ciuonzo, A. Montieri, V. Persico, and A. Pescapé, "Characterization and prediction of mobile-app traffic using Markov modeling," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 907–925, Mar. 2021.
11) Y. Syu and C.-M. Wang, "QoS time series modeling and forecasting for Web services: A comprehensive survey," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 926–944, Mar. 2021.
12) R. Pinciroli, A. Ali, F. Yan, and E. Smirni, "CEDULE+: Resource management for burstable cloud instances using predictive analytics," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 945–957, Mar. 2021.
13) L. Toka, G. Dobreff, B. Fodor, and B. Sonkoly, "Machine learning-based scaling management in kubernetes edge clusters," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 958–972, Mar. 2021.
14) H. Yu, Z. Chen, G. Sun, X. Du, and M. Guizani, "Profit maximization of online service function chain orchestration in an inter-datacenter elastic optical network," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 973–985, Mar. 2021.
15) D. Perdices, J. E. L. de Vergara, and J. Ramos, "Deep-FDA: Using functional data analysis and neural networks to characterize network services time series," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 986–999, Mar. 2021.
16) S. Park, A. Bhattacharya, Z. Yang, S. R. Das, and D. Samaras, "Mosaic: Advancing user quality of experience in 360-degree video streaming with machine learning," *IEEE Trans. Netw. Service Manag.*, vol. 18, no. 1, pp. 1000–1015, Mar. 2021.
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[4] N. Zincir-Heywood *et al.*, “Guest editorial: Special section on data analytics and machine learning for network and service management—Part I,” *IEEE Trans. Netw. Service Manag.*, vol. 17, no. 4, pp. 1971–1974, Dec. 2020.

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