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EDITORIAL

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Integration of Cloud, Internet of Things, and Big Data Analytics

1 | INTRODUCTION

Cloud computing, Internet of Things (IoT), and big data are three important technology trends affecting all the major enterprises across the world. All these three areas are successors of classical areas of data centers, sensor networks, and data processing and prediction solutions. However, the way industries, governments, and individuals are changing across the globe, cloud, IoT, and big data analytics are going to contribute a lot in future technology transformations.

We see that a number of past forecasts and anticipations hold true for the growing cloud computing adoption. A report such as Gartner[1] forecasts a heavy growth of around 17% in the overall revenues from public cloud computing infrastructure and related services in year 2019. Various cloud services contributing to this revenue include services such as cloud business process services (BPaaS), cloud application infrastructure services (PaaS), cloud application Services (SaaS), cloud management and security services, and cloud system infrastructure services (IaaS). Out of all these services, the major stakeholder with the highest revenue share is cloud application services, which are mostly SaaS services. These services provide variety of solutions to a number of domains including user computing, content management, hosting, analytics, and many more. The domain of cloud computing and its services are also seeing notable changes due to a sizable adoption of IoT environments and their increasing applications. A report in the work of Puranik[2] envisaged that IoT will play a major stake in extensions of cloud applications. This report also forecasts that the recent time will see a heavy usage of data analytics driven IoT services running is the cloud. The integration of cloud, IoT, and data analytics is quickly becoming a center of the technology support for a variety of applications starting from improved customer experience, accurate predictions to better supply chain management.

Coming to emerging IoT adoption, a major survey revealed that IoT will be a center of the upcoming technologies and will have the most impactful "machine-aided commerce" applications in coming five years from now.[3] The impact of IoT is envisaged in this report ahead of cloud computing and artificial intelligence. Gartner in a report[4] forecasted a number of trends related to IoT technologies and their role in shaping the current and upcoming businesses. They expect that there will be more than 20 billion IoT devices within two years from now. The report also anticipates a lack of trained data science specialists who can fully utilize the potential of these IoT devices. In particular, this report anticipates a 4:1 ratio between the devices and human beings to highlight the role of IoT devices.

We are seeing a growing role of data analytics technologies in all technology sectors including advertising, finance, market research, and many other areas. A detailed report by Gartner in the work of Laney and Jain[5] shows multiple faces of data analytics with a focus on its effects on various technical and nontechnical stakeholders of the industry. This report shows a number of important statistics and predictions including a major role of data analytics-based decisions and its dependency of IoT and cloud computing as enabler technologies.

There is a growing interest among the research communities and academic groups to pursue and solve various related research problems at the intersection point of three different areas of cloud, IoT, and data analytics. Buyya et al[6] showcase a detailed analysis of future directions and research problems of cloud computing. The authors list a number of challenges yet to be addressed, which include challenges related to scalability, security, heterogeneity, and economics. The authors also envisage a growing role of IoT and data analytics applications running in the cloud. A discussion in the work of CACM Staff[7] highlights the role of IoT, data security, machine learning, and cloud computing. Eugster et al[8] showcase that the growing computational requirements by big data analytics may even replace a single cloud with a cloud of clouds. A number of recent contributions address the growing security issues in amalgamation of cloud, IoT, and Big data. Kumarage et al[9] show applications of homomorphic encryption scheme to provide secure cloud-based data analytics for IoT applications. Newer intermediate node-based paradigms such as fog computing have also evolved to provide quick and scalable solutions to support IoT applications.[10]

Siow et al[11] provide a detailed treatment to the data analytics methods for IoT applications in the areas of health, transport, living, environment, and other industry related problems. In addition, authors provide a detailed taxonomy of predictive data analytics solutions with their objectives. On the other hand, Botta et al[12] provide a detailed perspective on integration of cloud and IoT technologies and the new form of "CloudIoT" applications. In addition, the authors detail various complementary aspects such as displacement, reachability, and role of big data while seeing this integration.

In the coming times, it is inevitable to see the success of any one of the three technology paradigms to deliver without the help of the other two. The role of these three paradigms is also very well suited where the cloud provides infrastructure, IoT devices work as real-time data and knowledge generators, and big data analytics to provide meaningful predictions. This Special Issue on "Integration of Cloud, IoT and Big Data Analytics" has five research contributions. These contributions focus on various important aspects of the intersection of these three paradigms.

2 | SUMMARY OF THE CONTRIBUTIONS

The first article of this special issue is titled Cloud-based video analytics using convolutional neural networks.[13] The authors in this contribution provide a video analytics approach using convolutions neural networks, which uses an "in-memory" distributed computing scheme on cloud infrastructure. The contribution highlights an object classification approach that performs a threshold-based comparison among the stored objects and the input objects in videos streams. The authors provide a detailed mathematical analysis of video analytics process with a focus on their "in-memory" distributed computing approach. The authors also provide a detailed description of experimentation performed on a spark-based private cloud platform. The authors also provide role of data size and computing node in the overall processing of the video data. The authors in this paper show a matching accuracy of 97%. A number of IoT applications are based on video and this contribution demonstrates the role of cloud infrastructure scalability in video data analytics.

The second article in this special issue is titled A middleware solution for integrating and exploring IoT and HPC capabilities.[14] The authors in this paper provide a new middleware solution, "JCL", for collaboration of IoT applications and high performance computing (HPC) facilities. The authors argue that there is a strong need of having middleware solutions for the emerging IoT devices and the computations on HPC resources. To address these issues, the authors showcase JCL middleware API that supports one API to program different device categories, supporting various programming models, interoperability among various IoT services, and security issues. The authors consider IoT tasks as HPC tasks and perform the processing in JCL. The authors state that the heterogeneity issues of IoT devices are addressed in JCL using Java-enabled Android and Arduino devices. To show the simplicity, authors demonstrate a small prototype IoT-HPC application in JCL with a focus on battery consumption studies. The middleware and related APIs are need of the hour for the IoT applications.

The third article in this special issue is on A multi-time steps ahead prediction approach for scheduling live migration in cloud data centers.[15] This contribution focuses on a prediction approach to anticipate the live virtual machine (VM) migration in cloud computing infrastructure. The authors in this contribution state that the short duration prediction decisions in the cloud infrastructure lack accuracy due to the dynamic nature of cloud resource management. The authors focus primarily on live VM migration problem as a prediction problem and assess linear and nonlinear methods for this purpose. The authors propose a multitime step-based recurrent neural network-based prediction approach to forecast CPU utilization and bandwidth data during a live migration. Authors evaluate single time step ahead and multitime step-ahead prediction algorithms for prediction of bandwidth and CPU data using recurrent neural network. The authors show simulation results for cloud infrastructure and reveal that the recurrent neural network-based approach outperforms various traditional prediction approaches.

The fourth article in this special issue is titled Evolutionary mutation testing for IoT with recorded and generated events.[16] The authors in this contribution testify the event processing language (EPL) in the context of IoT events using evolutionary mutation testing (EMT) approach. The authors argue that EPL is a suitable programming language of event-based IoT applications and its testing using EMT. The authors in this contribution focus on two research questions. The first question aims at the possibility of reducing the complexity of EMT beyond the random selections. The second question aims to test the suitability of IoT-TEG (test event generator). The authors address the first question by performing experiments and concluded that guided EMT helps in finding more strong mutants. On the other hand, the second question helps in evaluating IoT-TEG and the authors show that IoT-TEG can serve as a suitable automated alternative of handwritten generation in mutation testing and EMT.

Finally, the fifth article in this special issue is titled Reducing the network overhead of user mobility-induced virtual machine migration in mobile edge computing.[17] The authors in this work focus on mobile edge computing where the cloud resources are placed at the network edge. This not only helps the smartphones to extend their computation and storage capacity but also helps in achieving an improved latency. The authors in this work consider the cases of Cloud VM migrations from one edge cloud to another edge cloud owing to the user mobility and suggest improved VM migration algorithms to address the network overhead issues. The paper first details the network overheads involved in the VM migrations forced by mobility of smartphone users. The authors present a classification of user movement trajectory in the form of certain and uncertain moving trajectories. Based on these movement guidelines, the authors proposed two migration algorithms. M-Weight algorithm shows reduction in the network overhead for the VMs by assigning weights to different cloud data centers based on the latency requirements of the user. For uncertain trajectories, the authors propose an M-Predict algorithm to predict mobility.

We see that the set of articles compiled in this special issue focus on various facets of intersection of cloud computing, IoT, and data analytics. We are thankful to the authors for presenting their latest contributions in the form of these high-quality articles. We also show our gratitude toward the reviewers contributing to this special issue in the form of their time to ascertain quality peer reviews. At the end, we hope that the articles presented in this special issue will add a great value to the current research directions in the target area, open up more research problems, and benefit the readers.

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