# Cloud Computing and Distributed Systems (CLOUDS) Laboratory



Annual Report - 2022



School of Computing and Information Systems Faculty of Engineering and Information Technology The University of Melbourne, Australia

## **1. Director's Message**

I am pleased to report on the key activities and outcomes of **Clou**d Computing and **D**istributed **S**ystems (CLOUDS) Laboratory at the University of Melbourne, Australia during the academic year 2022, which has been another extraordinary year in terms of research quality and international recognition of its members. The Lab has consolidated its position as one of the world-leaders in developing innovative solutions for Cloud Computing. The highlights of research activities and outcomes in 2022 are:



- The Lab successfully hosted ARC research projects (Discovery and Linkage Infrastructure Projects) along with hosting two new research projects.
- Members of the CLOUDS Lab have authored 69 publications, which include 52 journal papers.
- The Lab's flagship Cloudbus Project has released various new modules for Aneka, CloudSim, iFogSim, and Fogbus. iFogSim, building on CloudSim, has emerged as a defacto toolkit for modelling and simulation of Fog and Edge computing environments. It has been used by several researchers in academia and industries around the world.
- Members have presented over 45 invited talks that include 23 keynotes delivered at international conferences/events held in Australia, India, Portugal, Italy, Thailand, China, and USA.
- The Lab successfully hosted research activities of over 25 scholars, which include 19 PhD students and 2 Research Fellows.
- In 2022 alone, our papers have attracted over 10700 citations (ref: Google Scholar). We are recognized again in 2022 as the "Cloud Architect of the Year 2022" by Oracle.
- IEEE Technical Committee on Cloud Computing (IEEE TCCLD) presented its 2022 "Outstanding PhD Thesis Award" to Dr. Mohammad Goudarzi for his PhD thesis.
- We are recognised as the Top Researcher in "Computing Systems" and "Software Systems" field (highest cited in top 20 journals over the past five years), The Australian Research Magazine 2023, The Australian, November 10, 2022.
- A list of the world's top 2% researchers complied by Stanford University after assessing scientists worldwide for research carried out over their careers across all disciplines ranks us as #1 for citation impact during the single calendar year 2021 and #2 for career-long citation impact up until the end of 2021 in Distributed Computing area.
- Members of the Lab have led community efforts such as (a) the organisation of conferences (e.g., IEEE Cloud 2021 in Spain) and (b) Editor-In-Chief of Journal of Software: Practice and Experience, which was established 50+ years ago.
- The Lab is always looking for talented, motivated, and dedicated "young" students and researchers to join its team. Please feel free to contact me with your ideas!

Sincerely yours,

ungor

Dr. Rajkumar Buyya, Redmond Barry Distinguished Professor Director, Cloud Computing and Distributed Systems (CLOUDS) Laboratory School of Computing and Information Systems The University of Melbourne, Australia Web: www.cloudbus.org

## 2. The Team

#### **Director:**

• Professor Rajkumar Buyya

#### **Research Staff/Academics:**

- Dr. Maria Rodriguez
- Dr. Muhammed Tawfiqul Islam
- Dr. Mohammed Goudarzi

#### **PhD Students**

- Ms. Samodha Pallewatta
- Ms. Amanda Jayanetti
- Mr. Kwangsuk Song
- Ms. Anupama Mampage
- Mr. Jie Zhao
- Mr. Ming Chen
- Ms. Shinu M. Rajagopal, Amrita University, India.
- Mr. Guangyao Zhou, University of Electronic Science and Technology of China
- Mr. Tharindu Bandara
- Mr. Siddharth Agarwal
- Mr. Thanh-Hoa Nguyen
- Ms. Kalyani Pendyala
- Mr. Yulun Huang
- Mr. Zhiyu Wang
- Ms. Duneehsa Fernando
- Mr. Jayath Seneviratne
- Mr. Chun Wei Lim
- Ms. Thakshila Imiya Mohottige

#### Collaborators

- Colleagues holding research grants with the Director.
- International Visitors
- Many collaborators involved in extending and using the Cloudbus software.

#### **International Visitors**

- Leila Fayez Ismail, UAE University, UAE, Oct. 2022-2023
- Patricia Arroba, Universidad Politécnica de Madrid, Spain, Nov 2022-Feb 2023.

## **3. Competitive Grants Funded Projects and Programs - Active**

## Australian Research Council (ARC)

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#### **Other National Grants**

 Soumya K. Ghosh (Indian lead) and Rajkumar Buyya (Australian lead), "Spatial Cloud Federation: Orchestration of Multiple Spatial Clouds for Efficient Provisioning of Spatial Services", SPARC (Scheme for Promotion of Academic and Research Collaboration), Ministry of Human Resource Development, Government of India, 2019-2022, Amount: Indian Rupees 52.8 Lakh (52,80,000).

#### Industry and Melbourne University Grants

- M. Rodriguez, R. Buyya, M. Sarvi, "Mobile Edge Computing (MEC) for Smart Transport Applications", FEIT Platform Interdisciplinary Funding Grant, 2021-2022. Amount: \$30,000.
- M. Rodriguez and R. Buyya, "Optimizing Deep Learning Clusters with Transient Capacity using Artificial Intelligence", Meta Platforms, Inc., USA, 2023. Amount: \$72,000.

# 4. Publications

Year Publication Type	2002	<b>'03</b>	<b>'04</b>	<b>'05</b>	<b>'06</b>	<b>'07</b>	<b>'08</b>	<b>'09</b>	ʻ10	'11	'12	'13	'14	'15	'16	'17	<b>'1</b> 8	'19	<b>'20</b>	<b>'21</b>	'22
Books/Proceedings	1	1	1	1	5	4	3	5	2	3	2	2	1	2	3	1	2	2	4	8	5
Journal Papers	6	1	4	5	6	4	10	13	8	9	15	17	17	17	24	31	43	47	36	42	52
Book Chapters	1	0	0	4	4	2	4	11	3	13	3	1	2	3	6	10	1	8	3	9	9
Conference Papers	4	7	9	16	15	24	22	27	15	14	12	6	14	21	9	11	15	20	12	10	3
Magazine Articles	0	0	1	2	4	2	0	1	2	1	0	5	2	3	1	1	1	0	1	1	0
Total	12	9	15	28	34	36	39	57	30	40	32	31	36	46	43	54	62	77	58	70	69

• The Lab publication record since its inception in 2002 highlighted in the Table below:

## **Books/Proceedings Edited**

- Souvik Pal, Debashis De, and Rajkumar Buyya (eds), <u>Artificial Intelligence-based Internet</u> of <u>Things Systems</u>, 509 pages, ISBN: 978-3-030-87058-4, Springer, Switzerland, January 2022.
- Rajkumar Buyya, Lalit Garg, Giancarlo Fortino, and Sanjay Misra (eds.), <u>New Frontiers in</u> <u>Cloud Computing and Internet of Things</u>, 408 pages, ISBN: 978-3-031-05527-0, Springer, Switzerland, October 2022.
- 3. Debashis De, Anwesha Mukherjee, Rajkumar Buyya (eds.), <u>Green Mobile Cloud</u> <u>Computing</u>, 320 pages, ISBN: 978-3-031-08037-1, Springer, Switzerland, October 2022.
- 4. Debahuti Mishra, Rajkumar Buyya, Prasant Mohapatra, and Srikanta Patnaik (eds), Proceedings of the International Conference on Intelligent and Cloud Computing (ICICC 2021, Bhubaneswar, India), ISBN: 978-981-16-9873-6, Springer, Singapore, 2022.
- Rajkumar Buyya, Susanna Munoz Hernandez, Ram Mohan Rao Kovvur, and T. Hitendra Sarma (eds), Proceedings of the International Conference on Computational Intelligence and Data Analytics (ICCIDA 2022, January 8-9, 2022, Hyderabad, India), ISBN: 978-981-19-3391-2, Springer, Singapore, 2022.

#### **Book Chapters**

- Bhanu Chander, Souvik Pal, Debashis De, and Rajkumar Buyya, <u>Artificial Intelligencebased Internet of Things for Industry 5.0</u>, Artificial Intelligence-based Internet of Things Systems, S. Pal, D. De, and R. Buyya (eds), 3-43pp, ISBN: 978-3-030-87058-4, Springer, Switzerland, January 2022.
- Mohammad Goudarzi, Shashikant Ilager, and Rajkumar Buyya, <u>Cloud Computing and Internet of Things: Recent Trends and Directions</u>, New Frontiers in Cloud Computing and Internet of Things, R. Buyya, L. Garg, G. Fortino, S. Misra (eds), 3-29pp, ISBN: 978-3-031-05527-0, Springer, Switzerland, October 2022.
- Niloofar Gholipour, Ehsan Arianyan, and Rajkumar Buyya, <u>Recent Advances in Energy-Efficient Resource Management Techniques in Cloud Computing Environments</u>, New Frontiers in Cloud Computing and Internet of Things, R. Buyya, L. Garg, G. Fortino, S. Misra (eds), 31-68pp, ISBN: 978-3-031-05527-0, Springer, Switzerland, October 2022.
- Md Anit Khan, Andrew P Paplinski Abdul Malik Khan, Manzur Murshed, and Rajkumar Buyya, <u>Multi-objective Dynamic Virtual Machine Consolidation Algorithm for Cloud Data</u> <u>Centers with Highly Energy Proportional Servers and Heterogeneous Workload</u>, New Frontiers in Cloud Computing and Internet of Things, R. Buyya, L. Garg, G. Fortino, S. Misra (eds), 69-106pp, ISBN: 978-3-031-05527-0, Springer, Switzerland, October 2022.
- Xunyun Liu, Yufei Lin, and Rajkumar Buyya, <u>Dynamic Resource-Efficient Scheduling in</u> <u>Data Stream Management Systems Deployed on Computing Clouds</u>, New Frontiers in Cloud Computing and Internet of Things, R. Buyya, L. Garg, G. Fortino, S. Misra (eds), 133-163pp, ISBN: 978-3-031-05527-0, Springer, Switzerland, October 2022.
- Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, <u>ITL: An</u> <u>Isolation-Tree based Learning of Features for Anomaly Detection in Networked Systems</u>, New Frontiers in Cloud Computing and Internet of Things, R. Buyya, L. Garg, G. Fortino, S. Misra (eds), 185-207pp, ISBN: 978-3-031-05527-0, Springer, Switzerland, October 2022.

- Anwesha Mukherjee, Debashis De, and Rajkumar Buyya, <u>Green Mobile Cloud Computing</u> for Industry 5.0, Green Mobile Cloud Computing, R. Buyya, De, D., Mukherjee, A., Buyya, R. (eds.), 3-20pp, ISBN: 978-3-031-08037-1, Springer, Switzerland, October 2022.
- Rajkumar Buyya, Sukhpal Singh Gill, Satish Narayana Srirama, Rami Bahsoon, and San Murugesan, <u>A Strategy for Advancing Research and Impact in New Computing Paradigms</u>, Green Mobile Cloud Computing, R. Buyya, De, D., Mukherjee, A., Buyya, R. (eds.), 297-308pp, ISBN: 978-3-031-08037-1, Springer, Switzerland, October 2022.
- Anwesha Mukherjee, Debashis De, and Rajkumar Buyya, <u>New Research Directions for</u> <u>Green Mobile Cloud Computing</u>, Green Mobile Cloud Computing, R. Buyya, De, D., Mukherjee, A., Buyya, R. (eds.), 309-320pp, ISBN: 978-3-031-08037-1, Springer, Switzerland, October 2022.

#### Journal Editorials

 Satish Srirama and Rajkumar Buyya, <u>Post Golden Jubilee Year of the Software Journal:</u> <u>New Research Trends and Strengthening Advisory Editorial Team</u>, Software: Practice and Experience (SPE), Volume 52, Issue 1, Pages: 3-4, ISSN: 0038-0644, Wiley Press, New York, USA, January 2022.

## **Journal Papers**

- Sukhpal Singh Gill, Adarsh Kumar, Harvinder Singh, Manmeet Singh, Kamalpreet Kaur, Muhammad Usman, and Rajkumar Buyya, <u>Quantum Computing: A Taxonomy, Systematic</u> <u>Review and Future Directions</u>, Software: Practice and Experience (SPE), Volume 52, Issue 1, Pages: 66-114, ISSN: 0038-0644, Wiley Press, New York, USA, January 2022.
- Zhiheng Zhong, Minxian Xu, Maria Alejandra Rodriguez, Chengzhong Xu, and Rajkumar Buyya, <u>Machine Learning-based Orchestration of Containers: A Taxonomy and Future</u> <u>Directions</u>, ACM Computing Surveys, Volume 54, No. 10s, Article No. 217, Pages: 1-35, ISSN: 0360-0300, ACM Press, New York, USA, January 2022.
- Anupama Mampage, Shanika Karunasekera, and Rajkumar Buyya, <u>A Holistic View on Resource Management in Serverless Computing Environments: Taxonomy and Future Directions</u>, ACM Computing Surveys, Volume 54, No. 11s, Article No. 222, Pages: 1-36, ISSN: 0360-0300, ACM Press, New York, USA, January 2022.
- Bushra Jamil, Humaira Ijaz, Mohammad Shojafar, Kashif Munir and Rajkumar Buyya, <u>Resource Allocation and Task Scheduling in Fog Computing and Internet of Everything</u> <u>Environments: A Taxonomy, Review, and Future Directions</u>, ACM Computing Surveys, Volume 54, No. 11s, Article No. 233, Pages: 1-38, ISSN: 0360-0300, ACM Press, New York, USA, January 2022.
- Rajeev Muralidhar, Renata Borovica-Gajic, and Rajkumar Buyya, <u>Energy Efficient</u> <u>Computing Systems: Architectures, Abstractions and Modeling to Techniques and</u> <u>Standards</u>, ACM Computing Surveys, Volume 54, No. 11s, Article No. 236, Pages: 1-37, ISSN: 0360-0300, ACM Press, New York, USA, January 2022.
- Zhicheng Cai and Rajkumar Buyya, <u>Inverse Queuing Model-Based Feedback Control for</u> <u>Elastic Container Provisioning of Web Systems in Kubernetes</u>, IEEE Transactions on Computers (TC), Volume 71, No. 2, Pages: 337-348, ISSN: 0018-9340, IEEE CS Press, Los Alamitos, CA, USA, February 2022.

- Shreshth Tuli, Sukhpal Singh Gill, Minxian Xu, Peter Garraghan, Rami Bahsoon, Schahram Dustdar, Rizos Sakellariou, Omer Rana, Rajkumar Buyya, Giuliano Casale, and Nicholas R. Jennings, <u>HUNTER: AI based Holistic Resource Management for Sustainable Cloud</u> <u>Computing</u>, Journal of Systems and Software (JSS), Volume 184, Pages: 1-15, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, February 2022.
- Thar Baker, Muhammad Asim, Hezekiah Samwini, Nauman Shamim, Mohammed M. Alani, and Rajkumar Buyya, <u>A Blockchain-based Fog-oriented Lightweight Framework for</u> <u>Smart Public Vehicular Transportation Systems</u>, Computer Networks, Volume 203, Pages: 1-19, ISSN: 1389-1286, Elsevier Press, Amsterdam, The Netherlands, February 2022.
- Shreshth Tuli, Shashikant Ilager, Kotagiri Ramamohanarao, and Rajkumar Buyya, <u>Dynamic Scheduling for Stochastic Edge-Cloud Computing Environments using A3C</u> <u>Learning and Residual Recurrent Neural Networks</u>, IEEE Transactions on Mobile Computing (TMC), Volume 21, Number 3, Pages: 940-954, ISSN: 1536-1233, IEEE Computer Society Press, USA, March 2022.
- Dawei Sun, Shang Gao, Xunyun Liu, and Rajkumar Buyya, <u>A Multi-Level Collaborative</u> <u>Framework for Elastic Stream Computing Systems</u>, Future Generation Computer Systems (FGCS), Volume 128, Pages: 117-131, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, March 2022.
- Tahseen Khan, Wenhong Tian, Shashikant Ilager, and Rajkumar Buyya, <u>Workload</u> <u>Forecasting and Energy state Estimation in Cloud Data Centres: ML-centric Approach</u>, Future Generation Computer Systems (FGCS), Volume 128, Pages: 320-332, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, March 2022.
- Forum Desai, Deepraj Chowdhury, Rupinder Kaur, Marloes Peeters, Rajesh Chand Arya, Gurpreet Singh Wander, Sukhpal Singh Gill, and Rajkumar Buyya, <u>HealthCloud: A System</u> for Monitoring Health Status of Heart Patients using Machine Learning and Cloud <u>Computing</u>, Internet of Things, Volume 17, Pages: 1-18, ISSN: 2542-6605, Elsevier, Amsterdam, The Netherlands. March 2022.
- Xindong You, Dawei Sun, Xueqiang Lv, Shang Gao, and Rajkumar Buyya, <u>MQDS: An</u> <u>Energy Saving Scheduling Strategy with Diverse QoS Constraints towards Reconfigurable</u> <u>Cloud Storage Systems</u>, Future Generation Computer Systems (FGCS), Volume 129, Pages: 252-268, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, April 2022.
- Premathas Somasekaram, Radu Calinescu, and Rajkumar Buyya, <u>High-Availability</u> <u>Clusters: A Taxonomy, Survey, and Future Directions</u>, Journal of Systems and Software (JSS), Volume 187, Pages: 1-32, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, May 2022.
- 15. Adarsh Kumar, Carlo Ottaviani, Sukhpal Singh Gill, and Rajkumar Buyya, <u>Securing the</u> <u>Future Internet of Things with Post-Quantum Cryptography</u>, Security and Privacy, Volume 5, Issue 2, Pages: 1-10, ISSN: 2475-6725, Wiley Press, New York, USA, March/April 2022.
- 16. Muhammed Tawfiqul Islam, Huaming Wu, Shanika Karunasekera, and Rajkumar Buyya, <u>SLA-based Scheduling of Spark Jobs in Hybrid Cloud Computing Environments</u>, IEEE Transactions on Computers (TC), Volume 71, No. 5, Pages: 1117-1132, ISSN: 0018-9340, IEEE CS Press, Los Alamitos, CA, USA, May 2022.
- Sadoon Azizi, Mohammad Shojafar, Jemal Abawajy, and Rajkumar Buyya, <u>Deadline-aware and Energy-efficient IoT Task Scheduling in Fog Computing Systems: A Semi-greedy Approach</u>, Journal of Network and Computer Applications (JNCA), Volume 201, Pages: 1-13, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, May 2022.
- 18. Muhammed Golec, Ridvan Ozturac, Zahra Pooranian, Sukhpal Singh Gill and Rajkumar Buyya, <u>iFaaSBus: A Security and Privacy based Lightweight Framework for Serverless</u>

<u>Computing using IoT and Machine Learning</u>, IEEE Transactions on Industrial Informatics, Volume 18, Number 5, Pages: 3522-3529, ISSN: 1551-3203, IEEE Press, New Jersey, USA, May 2022.

- Prabhakar Krishnan, Kurunandan Jain, Rajkumar Buyya, Pandi Vijayakumar, Anand Nayyar, Muhammad Bilal, and Houbing Song, <u>MUD-based Behavioral Profiling Security</u> <u>Framework for Software-defined IoT Networks</u>, IEEE Internet of Things Journal, Volume 9, Number 9, Pages: 6611-6622, ISSN: 2327-4662, IEEE Computer Society Press, USA, May 2022.
- 20. Izaz Ur Rahman, Hashim Ali, Muhammad Zakarya, Lee Gillam, Omer Rana, and Rajkumar Buyya, <u>epcAware: A Game-Based, Energy, Performance and Cost-Efficient Resource Management Technique for Multi-Access Edge Computing</u>, IEEE Transactions on Services Computing (TSC), Volume 15, Number 3, Pages: 1634-1648, ISSN: 1939-1374, IEEE Computer Society Press, USA, May/June 2022.
- Tianchen Shao, Deepraj Chowdhury, Sukhpal Singh Gill, Rajkumar Buyya, <u>IoT-Pi: A</u> <u>Machine Learning-based Lightweight Framework for Cost-effective Distributed Computing</u> <u>using IoT</u>. Internet Technology Letters, Volume 5, Issue 3, Pages: 1-6, ISSN:2476-1508, Wiley Press, New York, USA, May/June 2022.
- Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya, <u>QoS-aware Placement of</u> <u>Microservices-based IoT Applications in Fog Computing Environments</u>, Future Generation Computer Systems (FGCS), Volume 131, Pages: 121-136, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, June 2022.
- Mohammadreza Razian, Mohammad Fathian, Rami Bahsoon, Adel Nadjaran Toosi, and Rajkumar Buyya, <u>Service Composition in Dynamic Environments: A Systematic Review</u> <u>and Future Directions</u>, Journal of Systems and Software (JSS), Volume 188, Pages: 1-26, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, June 2022.
- 24. Sara Hassan, Rami Bahsoon, and Rajkumar Buyya, <u>Systematic Scalability Analysis for</u> <u>Microservices Granularity Adaptation Design Decisions</u>, Software: Practice and Experience (SPE), Volume 52, Issue 6, Pages: 1378-1401, ISSN: 0038-0644, Wiley Press, New York, USA, June 2022.
- Rajendra Kumar Dwivedi, Rakesh Kumar, and Rajkumar Buyya, <u>A Multi Agent based</u> <u>Energy and Fault aware Scheme for WSN of Hard-to-Reach Territories</u>, International Journal of Autonomous and Adaptive Communications Systems, Volume 15, Number 2, Pages: 126;139, ISSN: 1754-8632, Inderscience Publishers, Geneva, Switzerland, June 2022.
- 26. Prabhakar Krishnan, Kurunandan Jain, Krishnashree Achuthan, and Rajkumar Buyya, <u>Software-Defined Security-by-Contract for Blockchain-enabled MUD-aware Industrial IoT</u> <u>Edge Networks</u>, IEEE Transactions on Industrial Informatics, Volume 18, Number 10, Pages: 7068-7076, ISSN: 1551-3203, IEEE Press, New Jersey, USA, June 2021.
- Hang Wu, Zhicheng Cai, Yamin Lei, Jian Xu, and Rajkumar Buyya, <u>Adaptive Processing</u> <u>Rate based Container Provisioning for Meshed Micro-services in Kubernetes Clouds</u>, CCF Transactions on High Performance Computing, Volume 4, Number 2, Pages: 165-181, ISSN: 2524-4922, Springer, Germany, June 2022.
- Muhammed Tawfiqul Islam, Shanika Karunasekera, Rajkumar Buyya, <u>Performance and</u> <u>Cost-efficient Spark Job Scheduling based on Deep Reinforcement Learning in Cloud</u> <u>Computing Environments</u>, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 33, No. 7, Pages: 1695-1710, ISSN: 1045-9219, IEEE CS Press, USA, July 2022.
- 29. Awais Manzoor, Malik Ali Judge, Fahim Ahmed, Saif ullslam, and Rajkumar Buyya, Towards Simulating the Constraint-based Nature-inspired Smart Scheduling in Energy

<u>Intelligent Buildings</u>, Simulation Modelling Practice and Theory, Volume 118, Pages: 1-19, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, July 2022.

- 30. G S S Chalapathi, Vinay Chamola, Wafa Johal, Jagannath Aryal, and Rajkumar Buyya, <u>Energy and Latency Aware Mobile Task Assignment for Green Cloudlets</u>, Simulation Modelling Practice and Theory, Volume 118, Pages: 1-18, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, July 2022.
- Jaydeep Das, Shreya Ghosh, Anwesha Mukherjee, Soumya K. Ghosh, and Rajkumar Buyya, <u>RESCUE: Enabling Green Healthcare Services using Integrated IoT-Edge-Fog-Cloud Computing Environments</u>, Software: Practice and Experience (SPE), Volume 52, Issue 7, Pages: 1615-1642, ISSN: 0038-0644, Wiley Press, New York, USA, July 2022.
- 32. Jialei Liu, Shangguang Wang, Lianyong Qi, and Rajkumar Buyya, <u>Reliability-Enhanced</u> <u>Task Offloading in Mobile Edge Computing Environments</u>, IEEE Internet of Things Journal, Volume 9, Number 13, Pages: 10382-10396, ISSN: 2327-4662, IEEE Computer Society Press, USA, July 2022.
- 33. Ishu Gupta, Ashutosh Kumar Singh, Chung-Nan Lee, and Rajkumar Buyya, <u>Secure Data</u> <u>Storage and Sharing Techniques for Data Protection in Cloud Environments: A Systematic</u> <u>Review, Analysis, and Future Directions</u>, IEEE Access, Volume 10, Pages: 71247-71277, ISSN: 2169-3536, IEEE Press, New Jersey, USA, July 2022.
- Redowan Mahmud, Samodha Pallewatta, Mohammad Goudarzi, and Rajkumar Buyya, <u>iFogSim2: An Extended iFogSim Simulator for Mobility, Clustering, and Microservice</u> <u>Management in Edge and Fog Computing Environments</u>, Journal of Systems and Software (JSS), Volume 190, Pages: 1-17, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, August 2022.
- 35. Tahseen Khan, Wenhong Tian, Shashikant Ilager, Mingming Gong, and Rajkumar Buyya, <u>Machine Learning (ML)-Centric Resource Management in Cloud Computing: A Review and Future Directions</u>, Journal of Network and Computer Applications (JNCA), Volume 204, Pages: 1-17, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, August 2022.
- 36. Leila Ismail and Rajkumar Buyya, <u>Artificial Intelligence Applications and Self-Learning 6G</u> <u>Networks for Smart Cities Digital Ecosystems: Taxonomy, Challenges, and Future</u> <u>Directions</u>, Journal of Sensors, Volume 22, Number 15, Pages: 1-32, ISSN: 1424-8220, MDPI Press, Basel, Switzerland, August 2022.
- 37. Vikas Chouhan, Sateesh K. Peddoju, and Rajkumar Buyya, <u>dualDup: A Secure and Reliable Cloud Storage Framework to Deduplicate the Encrypted Data and Key</u>, Journal of Information Security and Applications, Volume 69, Pages: 1-16, ISSN: 2214-2126, Elsevier, Amsterdam, The Netherlands, September 2022.
- 38. Giannis Tziakouris, Carlos Mera-Gomez, Francisco Ramírez, Rami Bahsoon, and Rajkumar Buyya, <u>Market-Inspired Framework for Securing Assets in Cloud Computing</u> <u>Environments</u>, Software: Practice and Experience (SPE), Volume 52, Issue 9, Pages: 2005-2025, ISSN: 0038-0644, Wiley Press, New York, USA, September 2022.
- Jaydeep Das, Shreya Ghosh, Soumya K. Ghosh, and Rajkumar Buyya, <u>LYRIC: Deadline</u> and <u>Budget Aware Spatio-Temporal Query Processing in Cloud</u>, IEEE Transactions on Services Computing (TSC), Volume 15, Number 5, Pages: 2869-2882, ISSN: 1939-1374, IEEE Computer Society Press, USA, September/October 2022.
- 40. TianZhang He, Adel Nadjaran Toosi, and Rajkumar Buyya, <u>CAMIG: Concurrency-Aware</u> <u>Live Migration Management of Multiple Virtual Machines in SDN-enabled Clouds</u>, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 33, No. 10, Pages: 2318-2331, ISSN: 1045-9219, IEEE CS Press, USA, October 2022.
- 41. Huned Materwala, Leila Ismail, Raed M. Shubair, and Rajkumar Buyya, <u>Energy-SLA-</u> <u>Aware Genetic Algorithm for Edge-Cloud Integrated Computation Offloading in Vehicular</u>

<u>Networks</u>, Future Generation Computer Systems (FGCS), Volume 135, Pages: 205-222, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, October 2022.

- 42. Minghui Wu, Dawei Sun, Yijing Cui, Shang Gao, Xunyun Liu, and Rajkumar Buyya, <u>A State</u> <u>Lossless Scheduling Strategy in Distributed Stream Computing Systems</u>, Journal of Network and Computer Applications (JNCA), Volume 206, Pages: 1-16, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, October 2022.
- 43. Jie Sun, Tianyu Wo, Xudong Liu, Rui Cheng, Xudong Mou, Xiaohui Guo, Haibin Cai, and Rajkumar Buyya, <u>CloudSimSFC: Simulating Service Function Chains in Multi-Domain</u> <u>Service Networks</u>, Simulation Modelling Practice and Theory, Volume 120, Pages: 1-19, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, November 2022.
- 44. Dawei Sun, Yijing Cui, Minghui Wu, Shang Gao, and Rajkumar Buyya, <u>An Energy Efficient</u> and <u>Runtime-Aware Framework for Distributed Stream Computing Systems</u>, Future Generation Computer Systems (FGCS), Volume 136, Pages: 252-269, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, November 2022.
- 45. Adarsh Kumar, Anuraj Singh Yadav, Sukhpal Singh Gill, Haris Pervaiz, Qiang Ni and Rajkumar Buyya, <u>A Secure Drone-to-Drone Communication and Software Defined Drone</u> <u>Network-Enabled Traffic Monitoring System</u>, Simulation Modelling Practice and Theory, Volume 120, Pages: 1-27, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, November 2022.
- Khalid Elgazzar1, Haytham Khalil, Taghreed Alghamdi, Ahmed Badr, Ghadeer Abdelkader, Abdelrahman Elewah and Rajkumar Buyya, <u>Revisiting the Internet of Things:</u> <u>New Trends, Opportunities and Grand Challenges</u>, Frontiers in the Internet of Things, Pages: 1-18, DOI: doi.org/10.3389/friot.2022.1073780, Frontiers Media, Lausanne, Switzerland, November 2022.
- Deepika Saxena, Ashutosh Kumar Singh, and Rajkumar Buyya, <u>OP-MLB: An Online VM</u> <u>Prediction based Multi-objective Load Balancing Framework for Resource Management at</u> <u>Cloud Data Center</u>, IEEE Transactions on Cloud Computing (TCC), Volume 10, Number 4, Pages: 2804-2818, ISSN: 2168-7161, IEEE Computer Society Press, USA, October-December 2022.
- 48. Guangyao Zhou, Ruiming Wen, Wenhong Tian, and Rajkumar Buyya, <u>Deep</u> <u>Reinforcement Learning-based Algorithms Selectors for the Resource Scheduling in</u> <u>Hierarchical Cloud Computing</u>, Journal of Network and Computer Applications (JNCA), Volume 208, Pages: 1-17, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, December 2022.
- Leticia Duboc, Rami Bahsoon, Faisal Alrebeish, Carlos Mera-Gómez, Vivek Nallur, Rick Kazman, Philip Bianco, Ali Babar, and Rajkumar Buyya, <u>Systematic Scalability Modeling</u> of <u>QoS-Aware Dynamic Service Composition</u>, ACM Transactions on Autonomous and Adaptive Systems (TAAS), Volume 16, Number 3-4, Article No. 10, Pages: 1-39, ISSN:1556-4665, ACM Press, New York, USA, December 2022.
- 50. Shreya Ghosh, Anwesha Mukherjee, Soumya K. Ghosh, and Rajkumar Buyya, <u>STOPPAGE: Spatio-temporal Data Driven Cloud-Fog-Edge Computing Framework for</u> <u>Pandemic Monitoring and Management</u>, Software: Practice and Experience (SPE), Volume 52, Issue 12, Pages: 2700-2726, ISSN: 0038-0644, Wiley Press, New York, USA, December 2022.
- 51. Amanda Jayanetti, Saman Halgamuge, and Rajkumar Buyya, <u>Deep Reinforcement</u> <u>Learning for Energy and Time Optimized Scheduling of Precedence-constrained Tasks in</u> <u>Edge-Cloud Computing Environments</u>, Future Generation Computer Systems (FGCS), Volume 137, Pages: 14-30, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, December 2022.

52. Yamin Lei, Zhicheng Cai, Xiaoping Li, and Rajkumar Buyya, <u>State Space Model and Queuing Network based Cloud Resource Provisioning for Meshed Web Systems</u>, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 33, No. 12, Pages: 3787-3799, ISSN: 1045-9219, IEEE CS Press, USA, December 2022.

## **Conference Papers**

- Zhiyu Wang, Mohammad Goudarzi, Jagannath Aryal, and Rajkumar Buyya, <u>Container</u> <u>Orchestration in Edge and Fog Computing Environments for Real-Time IoT Applications</u>, Proceedings of the International Conference on Computational Intelligence and Data Analytics (ICCIDA 2022, Springer, Singapore), Hyderabad, India, January 8-9, 2022. -Keynote Paper.
- Nishant Hada, Sreenu Maloth, Chandrashekar Jatoth, Ugo Fiore, Sangeeta Sharma, Subrahmanyam Chatharasupalli and Rajkumar Buyya, <u>A Novel Recommendation System</u> for Vaccines using Hybrid Machine Learning Model, Proceedings of the 4th International Conference on Machine Intelligence and Signal Processing (MISP2022, Springer Nature), Raipur, India, March 12-14, 2022.
- Prateek Mahajan, Anusha Kumar, GSS Chalapathi, and Rajkumar Buyya, <u>EFTA: An Energy-efficient, Fault-Tolerant, and Area-optimized UAV Placement Scheme for Search Operations</u>, Proceedings of the IEEE INFOCOM 2022 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS, IEEE Press, USA), London, UK, May 2-5, 2022.

## 5. Invited Presentations and Outreach

#### **By the Lab Director:**

#### Keynote Talks at International Conferences

- Neoteric Frontiers in Cloud and Edge Computing, International Conference on Computational Intelligence and Data Analytics (ICCIDA 2022), Hyderabad, India, January 8-9, 2022.
- 2. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Advances in Distributed Computing and Machine Learning (ICADCML 2022), Warangal, India, January 15-16, 2022.
- Neoteric Frontiers in Cloud and Edge Computing, 14th International Conference on Future Computer and Communication (ICFCC 2022), Singapore, February 18-20, 2022.
- 4. Neoteric Frontiers in Cloud and Edge Computing, International E-Conference on Emerging Technologies in IT (IECET22), Surat, India, February 24-25, 2022.
- 5. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Applied Computational Intelligence and Analytics (ACIA-2022), NIT Raipur, India February 26-27, 2022.
- 6. Neoteric Frontiers in Cloud and Edge Computing, 14th International Conference on Computer and Automation Engineering (ICCAE 2022), Brisbane, Australia, March 25-27, 2022.
- Neoteric Frontiers in Cloud and Edge Computing, 7th International Conference on Internet of Things, Big Data and Security (IoTBDS 2022), Setubal, Portugal, April 22-24, 2022.
- Neoteric Frontiers in Cloud and Edge Computing, International Conference on Computational Intelligence and Smart Communication (ICCISC 2022), Dehradun, India, India, June 10-11, 2022.
- 9. Neoteric Frontiers in Cloud and Edge Computing, International Workshop on Big Data in Emergent Distributed Environments (BiDEDE 2022), In Conjunction with the 2022 ACM SIGMOD Conference, Philadelphia, USA, June 12-17, 2022.
- 10. Neoteric Frontiers in Cloud, Edge, Quantum Computing, 6th International Conference on High Performance Compilation, Computing and Communications (HP3C 2022), Jilin, China, June 23-25, 2022.
- 11. Neoteric Frontiers in Cloud, Edge, Quantum Computing, First International Conference on Intelligent Systems and Human Machine Collaboration (ICISHMC 2022), Thane, India, July 8-9, 2022.
- 12. New Frontiers in Cloud and Edge Computing, 6th International Conference on Big Data and Internet of Things (BDIOT 2022), Chongqing, China, August 12-14, 2022.
- 13. Sustainable Computing Panel, 16th IEEE International Conference on Service-Oriented System Engineering (IEEE SOSE 2022), San Francisco, USA, Aug 17, 2022.
- New Frontiers in Cloud and Edge Computing, International Conference on Recent Advances in Industry 4.0 Technologies (ICRAIT 2022), NIT Puducherry, India, September 16, 2022.
- 15. New Frontiers in Cloud and Edge Computing, International Conference on Blockchain and Distributed Systems Security (ICBDS 20229, Pune, India, September 17, 2022.
- New Frontiers in Cloud and Edge Computing, 6th International Conference on Algorithms, Computing and Systems (ICACS 2022), Larissa, Greece, September 16-18, 2022.
- 17. New Frontiers in Cloud and Edge Computing, 7th IEEE Cyber Science and Technology Congress (CyberSciTech 2022), Lamenzia, Italy, September 12-15, 2022.
- 18. New Frontiers in Cloud and Edge Computing, International Conference on Analytical and Computational Electronics (ICACE -2022), Kolkata, India, September 26-28, 2022.

- 19. New Frontiers in Cloud and Edge Computing, 14th International Conference on Advanced Computer Science and Information Systems (ICACSIS 2022), Jakarta, Indonesia, October 1-3, 2022.
- 20. New Frontiers in Cloud and Edge Computing, 3rd International Conference on Artificial Intelligence and Computer Engineering (ICAICE 2022), Dalian, China, November 11-13, 2022.
- 21. New Frontiers in Cloud, Edge and Quantum Computing, 7th IEEE International Conference on Parallel, Distributed and Grid Computing (PDGC-2022), Solan, India, November 25-27, 2022.
- 22. New Frontiers in Cloud, Edge and Quantum Computing, International Conference on Recent Advances in Computer Science and Engineering (ICRACSE-2022), Delhi, India, November 26-27, 2022.
- 23. New Frontiers in Cloud, Edge and Quantum Computing, 5th International Conference on Telecommunications and Communication Engineering (ICTCE 2022), Chengdu, China, November 28-30, 2022.
- 24. New Frontiers in Cloud, Edge and Quantum Computing, 5th IEEE Pune Section International Conference on Information, Implementation and Innovation in Technology (IEEE PuneCon2022), Pune, India, December 15-17, 2022.

#### National Conferences

- 1. AICTE Faculty Development Program on Machine Learning, Guru Nanak Dev Engineering College, Bidar, India, Jan. 5-11, 2022.
- 2. AICTE ATAL Academy FDP on Recent Developments in IoT, Institute of Engineering & Management, Kolkata, India, January 17, 2022.
- Computers and the Internet: Technological Progression and Applications (1840 to 2030), Department of Education in Science and Mathematics, National Council of Educational Research and Training (NCERT), New Delhi, India.February 11, 2022.
- 4. Faculty Development Program on Blockchain Technology, Indian Institute of Information Technology, Dharwad, India, February 28, 2022.
- 5. AICTE/ISTE Faculty Development Refresher Program on Internet of Things (IoT) Application, Bengal Institute of Technology, Kolkata, India, February 14-19, 2022.
- 6. Workshop on Intelligent Edge Computing for Cyber-Physical System and Cloud Computing, Indian Institute of Technology (IIT), Patna, India, March 5, 2022.
- 7. Cloud Computing, Emerging Areas In Line with National Education Policy (NEP 2020), All India Council for Technical Education (AICTE), New Delhi, India, August 18, 2022.
- 8. AICTE Faculty Development Programme (FDP) on Cloud and Fog Computing Platforms for Internet of Things Applications, National Institute of Technology, Warangal, India, September 19, 2022.
- 9. AICTE FDP on Blockchain Technology, Army Institute of Technology, Pune, India, October 17, 2022.
- 10. FDP Workshop on Cloud and Edge Computing, Joy University, Kanyakumari, India, December 12, 2022.
- 11. International Workshop on Cloud and Edge Computing, Sanjay Ghodawat University, Kolapur, India, December 28-29, 2022.

#### Seminars - in Cloud Computing area:

- 1. Neoteric Frontiers in Cloud and Edge Computing, IEEE Computer Society Region 10, Asia-Pacific, January 20, 2022.
- 2. Multi-Cloud Computing for Big Data Applications, Global Technology Outlook series, IBM, Worldwide (USA, Europe, Asia/India/Israel), May 26, 2022.
- 3. New Frontiers in Cloud and Edge Computing, Curtin University, Perth, Australia, Sept 7, 2022.
- 4. New Frontiers in Cloud and Edge Computing, GLA University, Mathura, India, September 15, 2022.

- 5. New Frontiers in Cloud and Edge Computing, Indian Institute of Technology (IIT) Kharagpur, India, September 22, 2015
- 6. New Frontiers in Cloud and Edge Computing, Jadavpur University, Kolkata, India, September 28, 2022.
- 7. New Frontiers in Cloud and Edge Computing, Chulalongkorn University, Bangkok, Thailand, September 29, 2022.
- 8. New Frontiers in Cloud and Edge Computing, Government Big Data Institute, Bangkok, Thailand, September 30, 2022.
- 9. New Frontiers in Cloud, Edge, and Quantum Computing, IEEE Computational Intelligence Society (CIS), Victorian Section, Australia, November 2, 2022.
- 10. New Frontiers in Cloud, Edge, and Quantum Computing, Digital University, Thiruvananthapuram, Kerala, India, Dec. 8, 2022.
- 11. New Frontiers in Cloud, Edge, and Quantum Computing, Amrita University, Amritapuri, Kerala, India, Dec. 14, 2022.
- 12. New Frontiers in Cloud, Edge, and Quantum Computing, MIT-ADT University, Pune, India, Dec. 16, 2022.
- 13. New Frontiers in Cloud, Edge, and Quantum Computing, Visvesvaraya Technological University (VTU), Belgaum, India, Dec. 31, 2022.

## 6. Selected Community Services

#### **By the Lab Director:**

#### **IEEE Computer Society**

- 1. Advisory Board, IEEE Technical Committee on Scalable Computing
- 2. IEEE Fellowship Selection Committee Member

#### Software: Practice and Experience (Wiley)

1. Editor in Chief (EiC), 2014-to date.

#### Journal Editorials

- Editorial Board Member, International Journal of Parallel, Emergent and Distributed Systems (IJPEDS), ISSN: 1744-5760, Taylor & Francis Group, UK, 2006-2013. IJPEDS), ISSN: 1744-5760, Taylor & Francis Group, UK, 2013-to date.
- 2. Co-Editor-in-Chief, Journal of Cloud Computing: Advances, Systems and Applications (JoCCASA), ISSN: 2192-113X, Springer, UK, 2012-2021.

#### **Conference Steering Committee**

- 1. Founder and Chair, IEEE/ACM International Symposium on Cluster, Cloud, and Grid Computing (CCGrid), 2001-to date.
- 2. Advisory Committee Member, International Conference on e-Science (e-Science), 2011to date.
- 3. Advisory Committee Member, IEEE International Conference on Cluster Computing (ClusterXY), 2011-to date.
- 4. Member, International Symposium on Computer Architecture and High Performance Computing, Brazil, 2005-to date.
- 5. Founder and Chair, IEEE/ACM International Conference on Utility and Cloud Computing (UCC) series, 2009-to date.

#### Conference Organisation/Program Committee Memberships

- 6. PC Chair, 31st International Conference on Computer Communications and Networks (ICCCN 2022), July 25-28, 2022, Honolulu, Hawaii, USA.
- 7. PC Chair, 2022 IEEE International Conference on Cloud Computing (CLOUD 2022), July 11-16, 2022, Barcelona, Spain.

#### **Community Information Sources**

- Maintained a Grid Computing Information Centre at: <u>http://www.gridcomputing.com</u>, whose newsletter mailing list has over 2500 members. This website is often ranked amongst top #4 sources for grid computing by Google search engine.
- Maintained a Cluster Computing Information Centre at: <u>http://www.buyya.com/cluster</u>

#### By Other Members:

#### Technical Program Committee Memberships + other Professional Services

\* Noted in their profile pages.

## 7. Members Profile and Activities

#### Member Self Profile: Mohammad Goudarzi

I joined the CLOUDS Lab at the University of Melbourne (UoM) in July 2018 as a PhD student and Research Assistant under the supervision of Prof. Rajkumar Buyya and Prof. Marimuthu Palaniswami. Recently, after my PhD graduation in June 2022, I joined the University of New South Wales (UNSW) Sydney as a Senior Research Associate (Senior Postdoc).

During my PhD career, I have published 10+ articles, contributed to two software systems, and mentored three MSc students.

My thesis received two "Best PhD Thesis Award" in 2022 from IEEE TCSC and IEEE TCCLD. Also, I have received the "Oracle Cloud Architect of the Year Award 2022" for the design and deployment of our new "*FogBus2*" resource



management framework (<u>Award, OCI Build and Deployed, OCI Blog Post</u>, and <u>Australian Financial</u> <u>Review (AFR)</u>).

I have published two articles in "IEEE Transactions on Mobile Computing (TMC)", among which one (*An Application Placement Technique for Concurrent IoT Applications in Edge and Fog Computing Environments*) is selected as "*ESI highly cited paper*" and is among the "*most popular papers*" published in the TMC. Besides, we designed and implemented an open-source software framework, "*FogBus2*", which is a new distributed container-based framework for resource management in Cloud/Fog/Edge computing environments. Besides, we extended and released the second version of the *iFogSim Simulation Toolkit*. Also, during my PhD career, I was awarded the "*Rowden White Scholarship*", a prestigious scholarship provided by the UoM to talented, high-quality PhD students.

I also worked as the Cyber Chair for 20<sup>th</sup> and 21<sup>st</sup> IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid), for which I received the "*IEEE Outstanding Service Award*".

My research interests include Distributed Systems, Cloud/Fog/Edge Computing, Internet of Things (IoT), Machine Learning, and Cybersecurity.

Further information can be found on my LinkedIn Profile and Google Scholar page.

## Member Self Profile: Samodha Pallewatta

I joined CLOUDS lab in February 2019, to pursue my PhD under the supervision of Prof. Rajkumar Buyya and Prof. Vassilis Kostakos at University of Melbourne.

Before starting my PhD, I obtained my bachelor's degree from University of Moratuwa majoring in Electronic and Telecommunication Engineering, in 2017. Afterwards I worked as a Software Engineer in Sri Lanka for almost 2 years, before joining CLOUDS lab.

My areas of interest include, Fog computing, Internet of Things, Fog computing resource and application scheduling and microservice-based application development. In my PhD research, I'm working on efficient application placement policies in Fog computing environments, I specially focus on challenges related to the placement of microservicesbased IoT applications within Fog environments.



List of my works are as follows:

• Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya," Placement of Microservicesbased IoT Applications in Fog Computing: A Taxonomy and Future Directions", arXiv preprint arXiv:2207.05399 (2022).

• Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya," Microservices based IoT Application Placement within Heterogeneous and Resource Constrained Fog Computing Environments", Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing, Pages: 71-81, Auckland, New Zealand, December 2-5, 2019.

• Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya," QoS-aware placement of microservices-based IoT applications in Fog computing environments", Future Generation Computer Systems (FGCS), Volume 131, Pages: 121-136, ISSN:0167-739X, June 2022.

• Redowan Mahmud, Samodha Pallewatta, Mohammad Goudarzi, and Rajkumar Buyya,"IFogSim2: An Extended iFogSim Simulator for Mobility, Clustering, and Microservice Management in Edge and Fog Computing Environments", Journal of Systems and Software (JSS)

Volume 190, ISSN: 0164-1212, August 2022.

For more information, please refer\_https://linkedin.com/in/samodha-pallewatta

## Member Self Profile: Amanda Jayanetti

I joined CLOUDS lab in February 2019, as a PhD student at the University of Melbourne, under the supervision of Prof. Rajkumar Buyya and Prof. Saman Halgamuge.

I received my bachelor's degree in Computer Science and Engineering from University of Moratuwa, in 2017. Prior to commencing my PhD studies, I worked as a Cloud engineer for 2 years at a leading IT organization that operates worldwide.

My areas of research include energy-efficient resource management in heterogeneous cloud computing environments. I'm particularly interested in harnessing the capabilities of artificial intelligence techniques for enhancing the resourceefficiency of cloud data centres.

For more information, please refer Google Scholar .



## Member Self Profile: Anupama Mampage

I joined the CLOUDS Lab as a PhD student in February 2020 under the supervision of Prof.

Rajkumar Buyya and Prof. Shanika Karunasekera. I completed by BSc Engineering (Hons) degree, specialized in Electronic and Telecommunication Engineering from the University of Moratuwa, Sri Lanka in 2017 and worked in the Software Industry as part of a Research and Development team at a large Telecommunication Provider in the country, prior to joining the lab.

Currently I am in the third year of my PhD studies and my research is focused on the aspect of autonomous resource management in serverless computing environments. I am interested in studying ways to optimize resource scheduling and scaling for applications deployed under this new computing model both in the cloud and fog environments. My research objectives are to identify resource management techniques which involve minimum user intervention and meet the QoS requirements of the user while maintaining high resource efficiency at the provider.



The first paper of my PhD research titled, "Deadline-aware Dynamic Resource Management in Serverless Computing Environments", was published in the proceedings of the CCGrid2021 conference. We also published the outcome of the survey and review work done on aspects of resource management in serverless computing environments, at the ACM Computing Surveys journal.

LinkedIn: www.linkedin.com/in/anupama-mampage

## Member Self Profile: Jie Zhao

I joined CLOUDS Lab in July 2020 at the University of Melbourne as a PhD student, under the supervision of Prof. Rajkumar Buyya and Dr Maria Rodriguez Read. My study is funded by the Melbourne Research Scholarship (MRS).

In 2005, I received my bachelor's degree in Electronic Engineering and Information Technology from Shanghai Normal University. After graduation, I worked for two years as a software engineer in Shanghai and Beijing until 2007. In July 2007, I came to Australia and completed a master's degree in information technology at the University of Melbourne in 2009.

Before joining the CLOUDS lab, I worked ten years for a midsize IT retailer enterprise in different roles as a senior software engineer, an IT infrastructure manager, and a CTO. I'm also an AWS certified solution architect. During my industry experience, I used hybrid-cloud and multi-cloud strategies to empower critical infrastructure and business applications, adopted Kubernetes and various cloud-native



technologies, and successfully transform a monolithic architecture into a modern microservice oriented architecture.

During my industry career, I developed vital interests in resource management and cloud computing. Remembering inspirations gave Prof. Buyya during my master's degree study, I came to him for pursuing a PhD. Currently, my research interest lies in the middle ground of cloud computing, resource management, artificial intelligence, and operations research. The broad goal is to identify and fill research gaps in AI/ML-powered autonomous workload management, resource management and operation in cloud computing environments.

#### Publications:

Jie Zhao, Maria A. Rodriguez, and Rajkumar Buyya, High-Performance Mining of COVID-19 Open Research Datasets for Text Classification and Insights in Cloud Computing Environments, Proceedings of the 13th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2020, IEEE CS Press, USA), Leicester, UK, Dec. 7-10, 2020.

Jie Zhao, Maria A. Rodriguez, and Rajkumar Buyya, A Deep Reinforcement Learning Approach to Resource Management in Hybrid Clouds Harnessing Renewable Energy and Task Scheduling, Proceedings of the 14th IEEE International Conference on Cloud Computing (IEEE Cloud 2021, IEEE CS Press, USA), September 5-10, 2021.

Profiles: Linked In: <u>https://www.linkedin.com/in/jie-zhao-64843765/</u> Website: <u>https://jiezhao.net/</u> Email: <u>zhao.j4@student.unimelb.edu.au</u> or j.z@ieee.org

## Member Self Profile: Ming Chen

I joined CLOUDS lab as a PhD student in Jan. 2021 under the primary supervision of Prof. Rajkumar Buyya and second supervision of Dr. Maria Alejandra Rodriguez. Before my PhD journey, I obtained my Bachelor's degree in Engineering from Hunan University in Sep. 2016, after which I worked as a research engineer and project manager at Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences. My previous working areas include speech recognition, FinTech, Cloud Robotics, etc. At Melbourne University, I mainly work in the areas of resource management and machine learning. My hobbies include Surfing, Tennis, Table Tennis and Hiking.



Papers:

- Wanlin Sun, Ming Chen\*, Cheng-zhong Xu, et al. "Semi-Supervised Anti-Fraud Models for Cash Pre-Loan in Internet Consumer Finance." IEEE ICPS 2019 (IEEE International Conference on Industrial Cyber Physical Systems), Taipei, Taiwan, May 2019
- Yuhang Zhang, Wensi Yang, Wanlin Sun, Kejjiang Ye, Ming Chen, Chengzhong Xu. "The Constrained GAN with Hybrid Encoding in Predicting Financial Behavior". AIMS 2019 (2019 International Conference on AI and Mobile Services), San Diego, USA. Jun. 2019 [Best Paper Award]
- Peng Lin, Kejiang Ye, Ming Chen, Cheng-Zhong Xu. "DCSA: Using Density-Based Clustering and Sequential Association Analysis to Predict Alarms in Telecommunication Networks". The 25th IEEE International Conference on Parallel and Distributed Systems (ICPADS 2019), Tianjin, China.

#### Member Self Profile: Qifan Deng

I obtained a bachelor of engineering and a bachelor of management at the Beijing Institute of

Technology. After that, I worked as a research assistant in Beijing Measurement and Control Technology Lab, as an engineer at Intel Corporation, as a software engineer at Huawei, and as a digital analyst at McKinsey & Company.

I joined the CLOUDS Laboratory in November 2020, as a master majoring in computer science at University of Melbourne.

I am ready to start my Ph.D. under the supervision of Rajkumar Buyya, working on a scalable distributed framework for scheduling and processing Internet of Things requests.

I hope my work can help with people's efficiency and creativity, thus, leave a small footprint as a contribution to human civilization progress.

GitHub: https://github.com/pancak3 LinkedIn: https://linkedin.com/in/qifan-deng



## Member Self Profile: Siddharth Agarwal

I joined CLOUDS lab as a Master of Science (Computer Science) student in March 2020, under the supervision of Dr. Buyya and Dr. Maria Rodriguez at

The University of Melbourne.

Prior to joining the CLOUDS Lab Group, I received my Bachelor of Technology degree with Honours from Jaypee Institute of Information Technology (JIIT), India, where I gained initial experiences in the field of AI/ML along with practical implementations. After graduating, I worked with IBM India for 15 months as an Associate System Engineer at Bangalore, India, with a focus towards software development and management of CMS (Content Management System) applications.

I completed my MSc mostly from overseas (India) in 2021, obtaining a place in Dean's Honors List 2021 and was awarded a Melbourne Research Scholarship for my Doctoral program. As part of my PhD program, I am



currently exploring the resource management and resource scheduling techniques in the domain of Serverless computing or Function-as-a-Service offering of Cloud Computing and investigating the application of AI/ML techniques for the same. My research focuses on data-driven and workload-aware function resource configurations and management.

For further information, please refer to my LinkedIn page: www.linkedin.com/in/siddharth26agarwal

#### Member Self Profile: Nguyen Thanh Hoa

I joined CLOUDS Labs in October 2021 to pursue my PhD under the supervision of Prof. Rajkumar Buyya and Dr. Muhammad Usman. My study is fully funded by the Vingroup Scholarship, managed by Vin University, Vietnam.

Before starting the PhD research, I obtained my Bachelor of Engineering in Computer Networks and Communications and my Master's in Computer Science (majoring in Cybersecurity) from Vietnam National University - Ho Chi Minh City (VNU-HCM) in 2016 and 2019, respectively. After graduating in 2016, I worked as a Teaching Assistant for four years and then became a Lecturer at the University of Information Technology, VNU-HCM. Besides, I also spent five months working as a research intern on the topic of Serverless and Multi-Access Edge Computing at the National Institute of Informatics (NII) in Tokyo, Japan, in 2020.



My research interests include Quantum Cloud Computing and Software Engineering, Serverless Computing, Federated Learning, and Cybersecurity. At CLOUDS Lab, I have been working on the Ph.D. research topic entitled "Serverless Resource Orchestration for Quantum Computing in Cloud Environments," focusing on designing a versatile and efficient serverless framework to optimize resource orchestration for quantum computing in heterogeneous cloud environments. In 2022, I mainly focused on developing **QFaaS**, an open-source **Q**uantum **F**unction-**a**s-**a**-**S**ervice framework that utilizes serverless computing and state-of-the-art software engineering techniques to empower quantum computing. More detail about QFaaS can be found <u>here.</u>

For more information and networking, please refer to my Linkedin or my website.

#### Member Self Profile: Tharindu B. Hewage

I joined the CLOUDs Lab in 2021 to pursue my doctorate degree under the supervision of Prof. Rajkumar Buyya, and Dr. Maria R. Rodriguez.

I come from the beautiful island nation of Sri Lanka. I love the area of physical science, especially mathematics and physics. Because of that, I was a keen student during my high school, where I graduated with distinctions whilst being ranked within the top 0.16% of more than twenty two thousand participants. I was awarded a merit scholarship to study at the University of Moratuwa, which is the topmost sought after university to study Engineering in Sri Lanka.



I have always been curious about machine intelligence, and how software systems contribute to that. This made me pursue my bachelors in Electronics and Telecommunication engineering, which allowed me to work with intelligent systems and implement them practically. I participated in several robotic competitions as an undergraduate and won multiple national awards. In 2018, I graduated with a first class Honors securing a cumulative GPA of 3.8 out of 4.0 for the final two academic years, in which the curriculum was more focused towards intelligent systems.

After graduation I joined WSO2, the largest open source integration software vendor in the world at that time, as a research and development Software Engineer. I gained more than three years of experience with enterprise software development in the domain of Identity and Access management. My work there was recognized at an exceptional level for consecutive years during the annual award ceremonies. Lately, the company started its transformation towards being cloud-native. My exposure to that developed a significant interest in distributed computing, especially in cloud computing.

Afterwards, I decided to apply for the CLOUDs lab at the University of Melbourne based on its world leading research expertise in distributed computing. I was awarded a fully-funded doctoral degree under the Graduate Research Scholarship scheme for high-achieving students. I am currently in the first year of my studies. I am interested in decentralization and intelligence in resource management algorithms that have the potential to solve emerging challenges of large-scale distributed computing systems, including the high energy consumption.

For more information, please kindly refer to my linkedIn profile. https://www.linkedin.com/in/tharindu-b-hewage/

Research interests: Distributed Algorithms, Intelligent Systems, Decentralized Systems, Machine Learning, Cloud Computing, Energy Efficiency

## Member Self Profile: Kalyani Pendyala

I am a PhD student part of CLOUDS LAB since January 2022

As part of Initial research work, I have started with a broader area of Software engineering and Cloud optimization. With Green Cloud and resource optimization as the larger goals of research my particular interest is around software architecture and software engineering methodologies to contribute the cloud resource optimization.

Spent a quality time on literature review around the most widely used Microservices architecture evolution, working in the area of Microservices and efficient ways of partitioning, placement, provisioning of Microservices.

I strongly believe optimization of resources shouldn't be confined to infrastructure and below layers, but it needs to be an responsible part of all peripheral layers like software application/ architecture and even software development principles.



#### Member Self Profile: Yulun Huang

I joined CLOUDS lab in December 2021 as a PhD student under the supervision of Prof. Rajkumar Buyya and Dr. Jagannath Aryal. I received my bachelor's degree in Mathematics and Statistics specialized in statistics in 2019 followed by a master's degree in Data Science in 2021 at the University of Melbourne. Prior to joining the CLOUDS labs, I spent 4 months working as an intern in the Melbourne Data Analytics Platform at the University of Melbourne focusing on developing a graphical live user requestable monitor output to help users improving their efficiency of using the Spartan, the high-performance computing unit at the university.



During my learning in data science, I obtain my interests in cloud computing and resource management and big data cloud. Currently, I am doing research on the bushfire problem with sensors and communications. As this is the first year in my PhD journey, I am looking forward to study more with the lab and my supervisors.

## Member Self Profile: Zhiyu Wang

I joined the CLOUDS Lab at the University of Melbourne in February 2022 as a PhD student under the supervision of Professor Rajkumar Buyya and Dr Mingming Gong.

Prior to joining the CLOUDS Lab, I obtained my Master's degree in Information Technology, specialisation in Artificial Intelligence, from the University of Melbourne in December 2021. I completed my Master's thesis, Integration of FogBus2 Framework with Container Orchestration Tools in Cloud and Edge Computing Environments, under the supervision of Professor Rajkumar Buyya.

I am currently in the second year of my PhD. I am now working on the IoT application's multi-objective optimization problem in edge and fog computing environment.



My research interests include cloud computing, fog computing, Internet of Things, deep learning, and reinforcement learning.

#### Member Self Profile: Duneesha Fernando

I joined the CLOUDS lab in April 2022, to pursue my PhD under the supervision of Prof. Rajkumar Buyya and Dr. Maria Rodriguez Read. My PhD study is fully funded by the Melbourne Graduate Research Scholarship.

In 2019, I completed my BSc (Hons) in Computer Science degree at the University of Colombo School of Computing (UCSC), Sri Lanka. Afterwards, I held the position of Assistant Lecturer at the same university for 1 year. Thereafter, I joined WSO2 which is world's #1 open source integration vendor and served its research team for 2 years, first as a Research Engineer, and then as a Senior Machine Learning Engineer.

At WSO2, I was a member of the team that developed a performance anomaly detection solution for microservices deployed in its EiPaaS platform. I commenced my PhD studies with the aim of further exploring along this research direction while building up on the practical knowledge already gained from the software industry.



My research interests include, performance anomaly detection, resource management, cloud/ edge/ fog computing and microservice-based IoT application development. In my PhD research, I'm working on anomaly-aware management of microservices-based IoT applications in edge computing environments. I'm particularly interested in addressing unique research challenges that arise when developing an autonomous anomaly-aware framework for the management of microservices-based IoT applications in edge computing environments.

For more information please refer, Linkedin : <u>https://www.linkedin.com/in/duneesha-fernando/</u> Google Scholar : <u>https://scholar.google.com.au/citations?user=azM61FMAAAAJ&hl=en</u>

## Member Self Profile: Chun Wei Lim

I joined CLOUDS Lab as a PhD student in November 2022, under the supervision of Dr. Maria Read and Prof. Rajkumar Buyya.

Before embarking on my PhD journey, I received my bachelor's degree in Computer Science at Nanyang Technological University, Singapore in 2018.

I started my career as a software developer, exposed to various tech stacks such as Spring, Spring Boot and React. We also use solutions offered by leading cloud services to further augment our platform. Because of our constant interaction with cloud services, I got myself certified as an AWS Solutions Architect – Associate to help my organisation design and implement efficient and effective cloud solutions.

My research interest is in machine learning, high performance and scalable computing.

I enjoy running and the occasional diving in my free time.



#### Member Self Profile: Thakshila Dilrukshi

I joined the CLOUDS Lab in November 2022 as a Ph.D. student Under the supervision of Professor Rajkumar Buyya and Associate Professor Artem Polyvyanny. I obtained my Master's in Computer Science degree specializing in Software Architecture, and my BSc Engineering (Hons) degree, specializing in Computer Science from the University of Moratuwa, Sri Lanka. Before joining the CLOUDS Lab, I worked in a leading IT company related to financial markets in Sri Lanka for 9 years.

Currently, I'm in the first year of my Ph.D. my research area is microservices and process mining. The project is mainly focusing on redesigning the legacy software into microservices by analyzing the software logs.

For more information, please refer: https://www.linkedin.com/in/thakshilad/



## Member Self Profile: Patricia Arroba

During my PhD, I joined the CLOUDS Lab. at the University of Melbourne as a visitor student, under the supervision of Professor Rajkumar Buyya. My research was funded by the European Network of Excellence on High Performance and Embedded Architecture and Compilation (HiPEAC). In 2017, I also visited the Matsuoka Lab. at the Tokyo Institute of Technology for a research stay supervised by Professor Satoshi Matsuoka. My mobility was funded by the European Commission under the Mundus Euro Erasmus Asia



Sustainable Energy Development (EM-EASED) program.

I received my PhD in Electronic Systems Engineering from the Technical University of Madrid (UPM), Spain, in 2017. My PhD Thesis, supervised by Prof. José M. Moya, Prof. José L. Ayala, and Prof. Rajkumar Buyya, obtained the cum laude distinction and the UPM PhD Extraordinary Award.

Since 2018, I have been an Assistant Professor at the Telecommunications Engineering School at UPM. In 2022, I was also a Visiting Professor at the CLOUDS Lab. funded by a HiPEAC collaboration grant.

I am co-author of more than 30 scientific publications in conferences and peer-reviewed international journals and I have been awarded the best paper award in the IV edition of the Novática journal. My research focuses on energy efficiency of Cloud and Edge infrastructures, considering computing and cooling systems and Smart Grid capabilities for mission-critical applications. In this field I have developed thermal and power models, modeling and simulation frameworks and optimization algorithms under dynamic operating conditions.

## 8. Selected Projects/Programs

# Cloudbus: A Toolkit for Market-Oriented Cloud Computing

#### Web: http://www.cloudbus.org/

The Cloud Computing and Distributed Systems (CLOUDS) Laboratory is a software research and innovation group at the University of Melbourne, Australia. The Lab is actively engaged in design and development of next-generation computing systems and applications that aggregate by dynamically leasing services of distributed resources depending on their availability, capability, performance, cost, and users' QoS requirements. The lab is working towards realising this vision through its two flagship projects: Gridbus and Cloudbus.

The Cloudbus project, an initiative that started in 2008 by the CLOUDS lab at the University of Melbourne, facilitates the realization of the above vision. The project developed innovative solutions for market-oriented Cloud computing. The current innovative developments include: (i) Aneka, a platform for developing and managing Cloud computing applications from market-oriented perspective; (ii) InterCloud, a framework for internetworking of Cloud service providers, dynamically creating federated computing environments, and scaling of distributed applications; (iii) CloudSim, a simulation framework that allows researchers to control every aspect of a Cloud environment: algorithms, platforms, and infrastructure; and (iv) Workflow Engine, a management platform that facilitates the creation, deployment and monitoring of complex applications modeled in a systematic and orderly manner in Cloud computing environments.

The Cloudbus project is engaged in the creation of open-source specifications, architecture and a reference toolkit implementation for market-oriented cloud computing. Some of our technologies serve as foundation for industrial solutions offered by Manjrasoft to its customers worldwide.

The research probes include:

- Market Oriented Cloud Architecture
- Enterprise Cloud Application Platform (Aneka)
- Cloud Service Broker
- Cloud Workflows and Scheduling
- Service Level Agreements & Resource Allocation Systems (Libra).
- Energy-Efficient Data Centers and Clouds
- Cloud Simulation Toolkit (CloudSim).
- Application Development Environments
- InterCloud Peering and Federation of Clouds
- Software Defined Networks
- Big Data
- Internet of Things (IoT)
- Fog and Edge Computing
- Application Targets include: Deed Learning, ECG Monitoring & Analysis, Data Mining & Business Analytics, and Brain Imaging (Dartmouth Medical School).
- Artificial intelligence (AI) for Next-Gen Cloud Computing
- Quantum Computing

#### Future Research is Driven By:

A Manifesto for Future Generation Cloud Computing: Research Directions for the Next Decade,

# Aneka: .NET-based Cloud Computing

Web: http://www.manjrasoft.com

ANEKA provides a set of services that make construction and development of Clouds and their applications as easy as possible without sacrificing flexibility, scalability, reliability and extensibility. It is commercialized through Manjrasoft, a startup company of the University of Melbourne. The key features supported by ANEKA are:

- A configurable and flexible execution platform (container) enabling -
  - Pluggable services;
  - Security implementations multiple authentication / authorization mechanisms such as role-based security and Windows domain-based authentication;
  - Multiple persistence options including RDBMS, SQL Express, MySQL and flat files;
- SDK (Software Development Kit) supporting multiple programming models including
  - Object-oriented Thread model,
  - Task model for legacy applications
  - Map Reduce model for data-intensive applications
  - Custom tools such as Design Explorer for parameter sweep studies
- Easy to use management tool for SLA and QoS negotiation and resource allocation.
- Cloudbrusting of application tasks across multiple Clouds (e.g., Azure and AWS)
- In 2021, we released Aneka 5.0 edition and updated to the latest .NET framework.



# **QoS-Oriented Cloud Workflow Engine**

Web: http://www.cloudbus.org/workflow

Infrastructure-as-a-Service (IaaS) clouds offer several advantages for the deployment of scientific workflows. They enable Workflow Management Systems (WMSs) to access a flexible and scalable infrastructure by leasing Virtual Machines (VMs). This allows workflows to be easily packaged and deployed and more importantly, enables WMSs to access a virtually infinite pool of VMs that can be elastically acquired and released and are charged on a pay-per-use basis. In this way, cloud resources can be used opportunistically based on the number and type of tasks that need to be processed at a given point in time. This is a convenient feature as it is common for the task parallelism of scientific workflows to significantly change throughout their execution. The resource pool can be scaled out and in to adjust the number of resources as the execution of the workflow progresses. This facilitates the fulfilment of the quality-of-service (QoS) requirements by allowing WMSs to fine-tune performance while ensuring the available resources are efficiently used.

We extend the Cloudbus WMS as a PaaS (Platform-as-a-Service) to support the cloud-computing paradigm. Specifically, the project aims to:

- Define an architectural framework and principles for the development of QoS-based workflow management in cloud environments,
- Develop QoS-based algorithms for scheduling scientific workflow applications,
- Develop policies and resource management algorithms tailored for the cloud resource model,
- Implement a prototype system by incorporating the algorithms and policies developed above, and
- Develop real world demonstrators in various scientific domains such as astronomy.



Fig. 1: Architecture of QoS-based workflow management and resource allocation system.

#### Some References:

- Muhammad Hilman, Maria Rodriguez, and Rajkumar Buyya, <u>Workflow-as-a-Service Cloud</u> <u>Platform and Deployment of Bioinformatics Workflow Applications</u>, Knowledge Management in Development of Data-Intensive Software Systems, I. Mistrik, M. Galster, B. Maxim, B. Tekinerdogan (eds), 205-228pp, ISBN: 978-1-003-00118-8, CRC Press, USA, June 2021.
- Muhammad Hilman, Maria Rodriguez, and Rajkumar Buyya, <u>Multiple Workflows</u> <u>Scheduling in Multi-tenant Distributed Systems: A Taxonomy and Future Directions</u>, ACM Computing Surveys, Volume 53, No. 1, Article No. 10, Pages: 1-39, ISSN: 0360-0300, ACM Press, New York, USA, May 2020.
- Maria A. Rodriguez, Ramamohanarao Kotagiri, and Rajkumar Buyya, <u>Detecting</u> <u>Performance Anomalies in Scientific Workflows using Hierarchical Temporal Memory</u>, Future Generation Computer Systems, Volume 88, Pages: 624-635, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, November 2018.
- Maria A. Rodriguez and Rajkumar Buyya, <u>Scheduling Dynamic Workloads in Multi-tenant</u> <u>Scientific Workflow as a Service Platforms</u>, Future Generation Computer Systems, Volume 79, No. 2, Pages: 739-750, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, February 2018.
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# The Green Cloud Project: Innovative Solutions for Energy-Efficient Cloud Computing

Web: http://www.cloudbus.org/greencloud

Traditionally, high-performance computing (HPC) community has focused on performance (speed). Since early 2000, several companies have started building Data Centers inspired by commodity HPC (cluster computing) systems-architecture for hosting/powering industrial applications including search engines such as Google. At the same time microprocessor vendors have not only doubled the number of transistors (and speed) every 18-24 months, but they have also doubled the power densities. That is, the tremendous increase in computer performance has come with an even greater increase in power usage. As a result operational cost of HPC systems including industrial Data Centre is rapidly growing. This is reflected from a statement by CEO of Google (Eric Schmit): "what matter most to Google is not speed but power, because data centers can consume as much electricity as a city."

The aim of Green Cloud Project is to develop high-end computing systems such as Clusters, Data Centers, and Clouds that allocate resources to applications hosting Internet services (e-Services) to meet not only users' quality of service requirements, but also minimise consumption of electric power. That is to, to improve power management and consumption by dynamically managing and configuring power-aware ability of system devices, such as processors, disks, and communication links.

#### Selected Publications:

- Anton Beloglazov and Rajkumar Buyya, Managing Overloaded Hosts for Dynamic Consolidation of Virtual Machines in Cloud Data Centers Under Quality of Service Constraints, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 24, No. 7, Pages: 1366-1379, IEEE CS Press, Los Alamitos, CA, USA, July 2013.
- Minxian Xu, Adel Nadjaran Toosi, and Rajkumar Buyya, <u>iBrownout: An Integrated Approach for Managing Energy and Brownout in Container-based Clouds</u>, IEEE Transactions on Sustainable Computing (T-SUSC), Volume 4, Number 1, Pages: 53-66, ISSN: 2377-3782, IEEE Computer Society Press, USA, January-March 2019.
- Amanda Jayanetti and Rajkumar Buyya, <u>J-OPT: A Joint Host and Network Optimization</u> <u>Algorithm for Energy-Efficient Workflow Scheduling in Cloud Data Centers</u>, Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2019, IEEE CS Press, USA), Auckland, New Zealand, Dec. 2-5, 2019.
- Shashikant Ilager, Rajeev Muralidhar, Kotagiri Rammohanrao, and Rajkumar Buyya, <u>A</u> <u>Data-Driven Frequency Scaling Approach for Deadline-aware Energy Efficient Scheduling</u> on <u>Graphics Processing Units (GPUs)</u>, Proceedings of the 20th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2020, IEEE CS Press, USA), Melbourne, Australia, May 11-14, 2020.
- Shashikant Ilager, Kotagiri Ramamohanarao, and Rajkumar Buyya, <u>Thermal Prediction for</u> <u>Efficient Energy Management of Clouds using Machine Learning</u>, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 32, No. 5, Pages: 1044-1056, ISSN: 1045-9219, IEEE CS Press, USA, May 2021.

# CloudSim: A Framework for Modeling and Simulation of Cloud Computing Infrastructures and Services

Web: http://www.cloudbus.org/cloudsim

Cloud computing emerged as the leading technology for delivering reliable, secure, fault-tolerant, sustainable, and scalable computational services, which are presented as Software, Infrastructure, or Platform as services (SaaS, IaaS, PaaS). Moreover, these services may be offered in private data centers (private clouds), may be commercially offered for clients (public clouds), or yet it is possible that both public and private clouds are combined in hybrid clouds.

These already wide ecosystem of cloud architectures, along with the increasing demand for energyefficient IT technologies, demand timely, repeatable, and controllable methodologies for evaluation of algorithms, applications, and policies before actual development of cloud products. Because utilization of real testbeds limits the experiments to the scale of the testbed and makes the reproduction of results an extremely difficult undertaking, alternative approaches for testing and experimentation leverage development of new Cloud technologies.

A suitable alternative is the utilization of simulations tools, which open the possibility of evaluating the hypothesis prior to software development in an environment where one can reproduce tests. Specifically in the case of Cloud computing, where access to the infrastructure incurs payments in real currency, simulation-based approaches offer significant benefits, as it allows Cloud customers to test their services in repeatable and controllable environment free of cost, and to tune the performance bottlenecks before deploying on real Clouds. At the provider side, simulation environments allow evaluation of different kinds of resource leasing scenarios under varying load and pricing distributions. Such studies could aid the providers in optimizing the resource access cost with focus on improving profits. In the absence of such simulation platforms, Cloud customers and providers have to rely either on theoretical and imprecise evaluations, or on try-and-error approaches that lead to inefficient service performance and revenue generation.

The primary objective of this project is to provide a generalized and extensible simulation framework that enables seamless modeling, simulation, and experimentation of emerging Cloud computing infrastructures and application services. By using CloudSim, researchers and industry-based developers can focus on specific system design issues that they want to investigate, without getting concerned about the low level details related to Cloud-based infrastructures such as Virtual Machines and Containers. CloudSim now support simulation of SDN and containers.

• In 2022, we release of CloudSim 6.0

#### Some References:

- Rodrigo N. Calheiros, Rajiv Ranjan, Anton Beloglazov, Cesar A. F. De Rose, and Rajkumar Buyya, CloudSim: A Toolkit for Modeling and Simulation of Cloud Computing Environments and Evaluation of Resource Provisioning Algorithms, Software: Practice and Experience (SPE), Volume 41, Number 1, Pages: 23-50, ISSN: 0038-0644, Wiley Press, New York, USA, January, 2011.
- Sareh Fotuhi Piraghaj, Amir Vahid Dastjerdi, Rodrigo N. Calheiros, and Rajkumar Buyya, ContainerCloudSim: An Environment for Modeling and Simulation of Containers in Cloud Data Centers, Software: Practice and Experience, Volume 47, Number 4, Pages: 505-521, ISSN: 0038-0644, Wiley Press, New York, USA, April 2017.
- Jungmin Son, TianZhang He and Rajkumar Buyya, <u>CloudSimSDN-NFV: Modeling and</u> <u>Simulation of Network Function Virtualization and Service Function Chaining in Edge</u> <u>Computing Environments</u>, Software: Practice and Experience (SPE), Volume 49, No. 12, Pages: 1748-1764, ISSN: 0038-0644, Wiley Press, New York, USA, December 2019.

# iFogSim: A Toolkit for Modeling and Simulation of Resource Management Techniques in Internet of Things, Edge and Fog Computing Environments

#### Web: http://www.cloudbus.org/cloudsim

Internet of Things (IoT) aims to bring every object (e.g. smart cameras, wearable, environmental sensors, home appliances, and vehicles) online, hence generating massive amounts of data that can overwhelm storage systems and data analytics applications. Cloud computing offers services at the infrastructure level that can scale to IoT storage and processing requirements. However, there are applications such as health monitoring and emergency response that require low latency, and delay caused by transferring data to the cloud and then back to the application can seriously impact their performances. To overcome this limitation, Fog computing paradigm has been proposed, where cloud services are extended to the edge of the network to decrease the latency and network congestion.

To realize the full potential of Fog and IoT paradigms for real-time analytics, several challenges need to be addressed. The first and most critical problem is designing resource management techniques that determine which modules of analytics applications are pushed to each edge device to minimize the latency and maximize the throughput. To this end, we need an evaluation platform that enables the quantification of performance of resource management policies on an IoT or Fog computing infrastructure in a repeatable manner.

We developed a simulator, called iFogSim, to model IoT and Fog environments and measure the impact of resource management techniques in terms of latency, network congestion, energy consumption, and cost.

In 2021: We released iFogSim 2.0 software.

#### Some References:

- Harshit Gupta, Amir Vahid Dastjerdi, Soumya K. Ghosh, and Rajkumar Buyya, iFogSim: A Toolkit for Modeling and Simulation of Resource Management Techniques in Internet of Things, Edge and Fog Computing Environments, Software: Practice and Experience, Volume 47, Issue 9, Pages: 1275-1296, Wiley Press, New York, USA, September 2017.
- Luiz F. Bittencourt, Javier Diaz-Montes, Rajkumar Buyya, Omer F. Rana, and Manish Parashar, Mobility-aware Application Scheduling in Fog Computing, IEEE Cloud Computing, Volume 4, No. 2, Pages: 34-43, ISSN: 2325-6095, IEEE Computer Society Press, USA, March-April 2017.
- Redowan Mahmud and Rajkumar Buyya, <u>Modelling and Simulation of Fog and Edge</u> <u>Computing Environments using iFogSim Toolkit</u>, Fog and Edge Computing: Principles and Paradigms, R. Buyya and S. Srirama (eds), ISBN: 978-111-95-2498-4, Wiley Press, New York, USA, January 2019.
- Redowan Mahmud, Satish Narayana Srirama, Kotagiri Ramamohanarao, and Rajkumar Buyya, <u>Profit-aware Application Placement for Integrated Fog-Cloud Computing</u> <u>Environments</u>, Journal of Parallel and Distributed Computing (JPDC), Volume 135, Pages: 177-190, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, January 2020.
- Mohammad Goudarzi, Huaming Wu, Marimuthu Palaniswami, and Rajkumar Buyya, <u>An</u> <u>Application Placement Technique for Concurrent IoT Applications in Edge and Fog</u> <u>Computing Environments</u>, IEEE Transactions on Mobile Computing (TMC), Volume 20, Number 4, Pages: 1298-1311, ISSN: 1536-1233, IEEE Computer Society Press, USA, April 2021.

# FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing

Web: https://github.com/Cloudslab/FogBus

The requirement of supporting both latency sensitive and computing intensive Internet of Things (IoT) applications is increasing the necessity for integrating Edge, Fog and Cloud infrastructures. Since, the integrated environments are distributed, centralized management of its resources is not feasible when latency sensitive data load is very high. Heterogeneity of resources and communication model further obstruct smooth execution of applications in integrated environments. In addition, Security of data and resources is also a very major concern of integrated Fog-Cloud environments.

There exist several works implementing software frameworks for integrating IoT-enabled systems, Fog and Cloud infrastructure. They;

- Barely support simultaneous execution of multiple applications and platform independence.
- Offer narrow scope to application developers and users to tune them framework according to individual requirements.
- Apply centralized techniques that eventually increase management time and service delay.
- Considers a few security aspects.

To overcome these problems, we have developed a lightweight framework for integrating IoT devices, Fog Computing and Cloud infrastructures. It offers platform independent application execution and node-to-node interaction overcoming resource heterogeneity. Moreover, it incorporates a Platform-as-a-Service (PaaS) model that assists both application developers and services providers. Based on FogBus, we have also developed a prototype application system for Sleep Apnea analysis in integrated IoT-Fog-Cloud environment. Furthermore, for ensuring data security, FogBus implements Blockchain, encryption and digital signature techniques.



#### References:

Shreshth Tuli, Redowan Mahmud, Shikhar Tuli, and Rajkumar Buyya, <u>FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing</u>, Journal of Systems and Software (JSS), Volume 154, Pages: 22-36, Elsevier Press, Amsterdam, The Netherlands, August 2019.
Shreshth Tuli, Nipam Basumatary, and Rajkumar Buyya, <u>EdgeLens: Deep Learning based</u> <u>Object Detection in Integrated IoT, Fog and Cloud Computing Environments</u>, Proceedings of the 4th IEEE International Conference on Information Systems and Computer Networks (ISCON 2019, IEEE Press, USA), Mathura, India, November 21-22, 2019.

[3] Qifan Deng, Mohammad Goudarzi and Rajkumar Buyya, <u>FogBus2: A Lightweight and</u> <u>Distributed Container-based Framework for Integration of IoT-enabled Systems with Edge and</u> <u>Cloud Computing</u>, Proceedings of the SIGMOD 2021 International Workshop on Big Data in Emergent Distributed Environments (BiDEDE 2021, ACM Press, USA), Xi'an, China, June 20-25, 2021.

# 9. Moments with Visitors, Colleagues and International Hosts



International School on Internet of Things & Edge AI: Computing, Communications and Systems, Sept 8- 12, 2022, Falerna (CS), Calabria, Italy





International Workshop on Cloud and Edge Computing, Sanjay Ghodawat University, Kolapur, India, December 28-29, 2022.