Cloud Computing and Distributed Systems (CLOUDS) Laboratory

www.cloudbus.org

Annual Report - 2021

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 2021, 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 2021 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 73 publications, which include 42 journal papers and 10 conference 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 de-facto 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 35 invited talks that include 23 keynotes delivered at international conferences/events held in Australia, India, Bahrain, France, Russia, Israel, China, and USA.
- The Lab successfully hosted research activities of over 25 scholars, which include 19 PhD students and 2 Research Fellows.
- In 2021 alone, our papers have attracted over 11200 citations (ref: Google Scholar). We are recognized again in 2021 as a "Web of Science Highly Cited Researcher".
- IEEE Technical Committee on Cloud Computing (IEEE TCCLD) presented its 2021 "Outstanding PhD Thesis Award" to Dr. Shashikant Ilager for his PhD thesis.
- We are recognised as "Lifetime Achiever" and "Superstar of Research" in "Engineering and Computer Science" discipline by the Australian Research Review 2021.
- 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 2020 and #2 for career-long citation impact up until the end of 2020 in Distributed Computing area.
- Members of the Lab have led community efforts such as (a) the organisation of conferences (e.g., CCGrid 2021 in Australia) 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,

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. Adel Toosi
- Dr. Maria Rodriguez

PhD Students

- Mr. Shashikant Ilager
- Mr. Jaydeep Das, Indian Institute of Technology, Kharagpur
- Mr. TianZhang He
- Mr. Mohammad Goudarzi
- Mr. Zhiheng Zhong
- Ms. Samodha Pallewatta
- Ms. Amanda Jayanetti
- Mr. Rajeev Muralidhar
- 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

Collaborators

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

International Visitors

- NIL – Thanks to COVID ☹

3. Competitive Grants Funded Projects and Programs - Active

Australian Research Council (ARC)

- R. Buyya, Algorithms and Software Systems for Management of Software-Defined Clouds, Discovery Project, Australian Research Council (ARC), 2016-2021. Amount: $410,000.
- D. Tao, B. Vucetic, R. Kotagiri, E. Nebot, X. Lin, Y. Gao, M. Bennamoun, R. Buyya, T. Baldwin, S. Williams, J. Yuan, and M. Pagnucco, "Whopping Volta GPU Cluster Transforming Artificial Intelligence Research", Linkage Infrastructure, Equipment and Facilities (LIEF) grant, Australian Research Council (ARC), Australia, 2020/2021. Amount: $900,000.

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

- R. Borovica-Gajic and R. Buyya, "Experimental Micro Datacenter Infrastructure for Green Cloud Computing and Energy", Research Initiatives Fund (RIF), 2021. Amount: $95,000.
- M. Rodriguez, R. Buyya, M. Sarvi, "Mobile Edge Computing (MEC) for Smart Transport Applications", FEIT Platform Interdisciplinary Funding Grant, 2021. Amount: $30,000.

4. Publications

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

Year / Publication Type	2002	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21
Books/Proceedings	1	1	1	1	5	4	3	5	2	3	2	2	1	2	3	1	2	2	4	8
Journal Papers	6	1	4	5	6	4	10	13	8	9	15	17	17	17	24	31	43	47	36	42
Book Chapters	1	0	0	4	4	2	4	11	3	13	3	1	2	3	6	10	1	8	3	9
Conference Papers	4	7	9	16	15	24	22	27	15	14	12	6	14	21	9	11	15	20	12	10
Magazine Articles	0	0	1	2	4	2	0	1	2	1	0	5	2	3	1	1	1	0	1	1
Total	12	9	15	28	34	36	39	57	30	40	32	31	36	46	43	54	62	77	58	70

Books/Proceedings Edited

1. Jitendra Kumar, Ashutosh Kumar Singh, Anand Mohan, and Rajkumar Buyya, Machine Learning for Cloud Management, ISBN: 9780367626488, CRC Press, USA, November 2021.
2. Anwesha Mukherjee, Debashis De, Soumya K. Ghosh, Rajkumar Buyya (eds.), Mobile Edge Computing, 605 pages, ISBN: 978-3-030-69895-9, Springer, USA, November 2021.
3. Harvinder Singh Saini, Rishi Sayal, Govardhan Aliseri, and Rajkumar Buyya (editors), Innovations in Computer Science and Engineering: Proceedings of the 8th International Conference, ISBN: 978-981-334-542-3, Springer, Singapore, February 2021.
4. Chhabi Rani Panigrahi, Bibudhendu Pati, Prasant Mohapatra, Rajkumar Buyya, Kuan-Ching Li (editors), Progress in Advanced Computing and Intelligent Engineering: Proceedings of the 4th International Conference (ICACIE 2018), ISBN: SBN 978-981-15-6584-7, Springer Nature, Singapore, 2021.
5. Debasis Giri, Rajkumar Buyya, S. Ponnusamy, Debashis De, Andrew Adamatzky, and Jemal H. Abawajy, Proceedings of the Sixth International Conference on Mathematics and Computing (ICMC 2020, Gangtok, Sikkim, India), Advances in Intelligent Systems and Computing 1262, ISBN 978-981-15-8060-4, Springer, Switzerland, 2021.
6. Yogesh L. Simmhan, Blesson Varghese, Lena Mashayekhy, Rajkumar Buyya, and Omer F. Rana, Proceedings of the 5th IEEE International Conference on Fog and Edge Computing (ICFEC 2021, May 10-13, 2021, Melbourne, Australia), ISBN 978-1-6654-0291-0, IEEE CS Press, Los Alamitos, CA, USA, 2021.
7. Laurent Lefevre, Stacy Patterson, Young Choon Lee, Haiying Shen, Shashikant Ilager, Mohammad Goudarzi, Adel N. Toosi, and Rajkumar Buyya, Proceedings of the 21th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2021, May 10-13, 2021, Melbourne, Australia), ISBN 978-1-7281-9586-5, IEEE CS Press, Los Alamitos, CA, USA, 2021.
8. Jyotsna Kumar Mandal, Rajkumar Buyya, and Debashis De, Proceedings of 2nd International Conference on Advanced Computing Applications (ICACA 2021, Kolkata, India), ISBN: 978-981-16-5206-6, Springer, Switzerland, 2021.

Book Chapters

9. G.S.S. Chalapathi, Vinay Chamola, Aabhaas Vaish, and Rajkumar Buyya, Industrial Internet of Things (IIoT) Applications of Edge and Fog Computing: A Review and Future Directions, Fog/Edge Computing For Security, Privacy, and Applications, Jie Wu and Wei Chang (eds), 293-325pp, ISBN: 978-3-030-57327-0, Springer Nature, Switzerland, January 2021.
10. Muhammad Hilman, Maria Rodriguez, and Rajkumar Buyya, Workflow-as-a-Service Cloud Platform and Deployment of Bioinformatics Workflow Applications, 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.

11. Linna Ruan, Shaoyong Guo, Xuesong Qiu, Rajkumar Buyya, [Fog Computing for Smart Grids: Challenges and Solutions](#), Electric Vehicle Integration in a Smart Microgrid Environment, M. Alam and M. Krishnamurthy (eds), 7-32pp, ISBN: 9780367423919, CRC Press, USA, August 2021.

12. Meeniga Sriraghavendra, Priyanka Chawla, Huaming Wu, Sukhpal Singh Gill, and Rajkumar Buyya, [DoSP: A Deadline-Aware Dynamic Service Placement Algorithm for Workflow-Oriented IoT Applications in Fog-Cloud Computing Environments](#), Energy Conservation Solutions for Fog-Edge Computing Paradigms, R. Tiwari, M. Mittal, and L. Goyal (eds), 21-47pp, ISBN: 978-981-16-3450-5, Springer, Switzerland, September 2021.

13. Anwesha Mukherjee, Debashis De, Soumya Kanti Ghosh, and Rajkumar Buyya, [Introduction to Mobile Edge Computing](#), Mobile Edge Computing, A. Mukherjee, D. De, S. Ghosh, and R. Buyya (eds), 3-19pp, ISBN: 978-3-030-69895-9, Springer, USA, November 2021.

14. Jaydeep Das, Soumya K. Ghosh, and Rajkumar Buyya, [Geospatial Edge-Fog Computing: A Systematic Review, Taxonomy, and Future Directions](#), Mobile Edge Computing, A. Mukherjee, D. De, S. Ghosh, and R. Buyya (eds), 47-69pp, ISBN: 978-3-030-69895-9, Springer, USA, November 2021.

15. Minxian Xu, Chengxi Gao, Shashikant Ilager, Huaming Wu, Chengzhong Xu, and Rajkumar Buyya, [Green-aware Mobile Edge Computing for IoT: Challenges, Solutions and Future Directions](#), Mobile Edge Computing, A. Mukherjee, D. De, S. Ghosh, and R. Buyya (eds), 145-164pp, ISBN: 978-3-030-69895-9, Springer, USA, November 2021.

16. Redowan Mahmud, Adel N Toosi, Maria Alejandra Rodriguez, Sharat Chandra Madanapalli, Vijay Sivaraman, Len Sciacca, Christos Sioutis, and Rajkumar Buyya, [Software-Defined Multi-domain Tactical Networks: Foundations and Future Directions](#), Mobile Edge Computing, A. Mukherjee, D. De, S. Ghosh, and R. Buyya (eds), 183-227pp, ISBN: 978-3-030-69895-9, Springer, USA, November 2021.

17. Kamran Sattar Awaisi, Assad Abbas, Samee U. Khan, Redowan Mahmud, and Rajkumar Buyya, [Simulating Fog Computing Applications using iFogSim Toolkit](#), Mobile Edge Computing, A. Mukherjee, D. De, S. Ghosh, and R. Buyya (eds), 565-590pp, ISBN: 978-3-030-69895-9, Springer, USA, November 2021.

Journal Editorials

18. Rajkumar Buyya, [Golden Jubilee Year of the Software Journal: Celebrating its Vision, Ground-breaking Contributions and Impact](#), Software: Practice and Experience, Volume 51, Number 1, Pages: 3-4, ISSN: 0038-0644, Wiley Press, New York, USA, January 2021.

19. Giancarlo Fortino, Rajkumar Buyya, Min Chen, and Francisco Herrera, [Special Issue on Methods and Infrastructures for Data Mining at the Edge of Internet of Things](#), IEEE Internet of Things Journal, Volume 8, Number 13, Pages: 10220-10221, ISSN: 2327-4662, IEEE Computer Society Press, USA, July 2021.

20. Shashikant Ilager, Vlado Stankovski, Shrideep Pallickarar, Rajkumar Buyya, [Elastic Computing from Edge to the Cloud Environments](#), Software: Practice and Experience, Volume 51, Number 9, Pages: 1849-1851, ISSN: 0038-0644, Wiley Press, New York, USA, September 2021.

Journal Papers

21. Gopal Rai, G R Gangadharan, Vineet Nair, and Rajkumar Buyya, [Web Service Interaction Modeling and Verification Using Recursive Composition Algebra](#), IEEE Transactions on Services Computing (TSC), Volume 14, Number 1, Pages: 300-314, ISSN: 1939-1374, IEEE Computer Society Press, USA, January/February 2021.

22. Jitendra Kumar, Ashutosh Kumar Singh, and Rajkumar Buyya, [Self Directed Learning based Workload Forecasting Model for Cloud Resource Management](#), Information

Sciences: An International Journal, ISSN: 0020-0255, Volume 543, Pages: 345-366, Elsevier Science, Amsterdam, The Netherlands, January 2021.

23. Ayaz Ali Khan, Muhammad Zakarya, Izaz Ur Rahman, Rahim Khan, and Rajkumar Buyya, HeporCloud: An Energy and Performance Efficient Resource Orchestrator for Hybrid Heterogeneous Cloud Computing Environments, Journal of Network and Computer Applications (JNCA), Volume 173, Pages: 1-27, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, January 2021.

24. Anwesha Mukherjee, Shreya Ghosh, Aabhas Behere, Soumya K. Ghosh, and Rajkumar Buyya, Internet of Health Things (IoHT) for Personalized Health Care using Integrated Edge-Fog-Cloud Network, Journal of Ambient Intelligence and Humanized Computing, Volume 12, Number 1, Pages: 943-959, ISSN: 1868-5137, Springer Science+Business Media, Berlin, Germany, January 2021.

25. Chubo Liu, Kenli Li, Keqin Li, and Rajkumar Buyya, A New Cloud Service Mechanism for Profit Optimizations of a Cloud Provider and Its Users, IEEE Transactions on Cloud Computing (TCC), Volume 9, Number 1, Pages: 14-26, ISSN: 2168-7161, IEEE Computer Society Press, USA, January-March 2021.

26. Caesar Wu, Adel N. Toosi, Rajkumar Buyya, and Kotagiri Ramamohanarao, Hedonic Pricing of Cloud Computing Services, IEEE Transactions on Cloud Computing (TCC), Volume 9, Number 1, Pages: 182-196, ISSN: 2168-7161, IEEE Computer Society Press, USA, January-March 2021.

27. Adarsh Kumar, Kriti Sharma, Harvinder Singh, Sagar Gupta Naugriya, Sukhpal Singh Gill, and Rajkumar Buyya, A Drone-based Networked System and Methods for Combating Coronavirus Disease (COVID-19) Pandemic, Future Generation Computer Systems (FGCS), Volume 115, Pages: 1-19, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, February 2021.

28. Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, ADRL: A Hybrid Anomaly-aware Deep Reinforcement Learning-based Resource Scaling in Clouds, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 32, No. 3, Pages: 514-526, ISSN: 1045-9219, IEEE CS Press, USA, March 2021.

29. Rajendra Kumar Dwivedi, Rakesh Kumar, and Rajkumar Buyya, Gaussian Distribution-Based Machine Learning Scheme for Anomaly Detection in Healthcare Sensor Cloud, International Journal of Cloud Applications and Computing, Volume 11, No. 1, Pages: 52-72, ISSN: 2156-1834, IGI Press, USA, January-March 2021.

30. Mohammadreza Razian, Mohammad Fathian, Huaming Wu, Ahmad Akbari, and Rajkumar Buyya, SAIoT: Scalable Anomaly-aware Services Composition in CloudIoT Environments, IEEE Internet of Things Journal, Volume 8, Number 5, Pages: 3665-3677, ISSN: 2327-4662, IEEE Computer Society Press, USA, March 2021.

31. Babar Ali, Muhammad Adeel Pasha, Saif ul Islam, Houbing Song, and Rajkumar Buyya, A Volunteer-Supported Fog Computing Environment for Delay-Sensitive IoT Applications, IEEE Internet of Things Journal, Volume 8, Number 5, Pages: 3822-3830, ISSN: 2327-4662, IEEE Computer Society Press, USA, March 2021.

32. Mohammad Goudarzi, Huaming Wu, Marimuthu Palaniswami, and Rajkumar Buyya, An Application Placement Technique for Concurrent IoT Applications in Edge and Fog Computing Environments, IEEE Transactions on Mobile Computing (TMC), Volume 20, Number 4, Pages: 1298-1311, ISSN: 1536-1233, IEEE Computer Society Press, USA, April 2021.

33. Xiaogang Wang, Jian Cao, Dingyu Yang, Zhen Qin, and Rajkumar Buyya, Online Cloud Resource Prediction via Scalable Window Waveform Sampling on Classified Workloads, Future Generation Computer Systems (FGCS), Volume 117, Pages: 338-358, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, April 2021.

34. Shashank Srivastava, Sandeep Saxena, Rajkumar Buyya, Manoj Kumar, Achyut Shankar, and Bharat Bhushan, CGP: Cluster-based Gossip Protocol for Dynamic Resource Environment in Cloud, Simulation Modelling Practice and Theory, Volume 108, Pages: 1-23, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, April 2021.

35. Devki Nandan Jha, Saurabh Garg, Prem Prakash Jayaraman, Rajkumar Buyya, Zheng Li, Graham Morgan, and Rajiv Ranjan, A Study on the Evaluation of HPC Microservices in

Containerized Environment, Concurrency and Computation: Practice and Experience (CCPE), Volume 33, No. 7, Pages: 1-18, ISSN: 1532-0626, Wiley Press, New York, USA, April 2021.

36. Wenjuan Li, Shihua Cao, Keyong Hu, Jian Cao, and Rajkumar Buyya, Blockchain-Enhanced Fair Task Scheduling for Cloud-Fog-Edge Coordination Environments: Model and Algorithm, Journal of Security and Communication Network, Volume 2021, Article ID 5563312, Pages: 1-18, Wiley and Hindawi Publishing Corporation, New York, USA, April 2021.

37. Prabhakar Krishnan, Kurunandan Jain, Pramod George Jose, Krishnashree Achuthan, and Rajkumar Buyya, SDN Enabled QoE and Security Framework for Multimedia Applications in 5G Networks, ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM), Volume 17, No. 2, Article No. 39, Pages: 1-29, ISSN:1551-6857, ACM Press, New York, USA, April 2021.

38. Shashikant Ilager, Kotagiri Ramamohanarao, and Rajkumar Buyya, Thermal Prediction for Efficient Energy Management of Clouds using Machine Learning, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 32, No. 5, Pages: 1044-1056, ISSN: 1045-9219, IEEE CS Press, USA, May 2021.

39. Hashim Ali, Muhammad Zakarya, Izaz Ur Rahman, Ayaz Ali Khan, and Rajkumar Buyya, FollowMe@LS: Electricity Price and Source Aware Resource Management in Geographically Distributed Heterogeneous Datacenters, Journal of Systems and Software (JSS), Volume 175, Pages: 1-21, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, May 2021.

40. Anubha Aggrawal, Neetesh Kumar, Deo Prakash Vidyarthi, and Rajkumar Buyya, Fog-Integrated Cloud Architecture enabled Multi-Attribute Combinatorial Reverse Auctioning Framework, Simulation Modelling Practice and Theory, Volume 109, Pages: 1-22, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, May 2021.

41. Khaled Alwasel, Rodrigo N. Calheiros, Saurabh Garg, Rajkumar Buyya, Mukaddim Pathan, Dimitrios Georgakopoulos, and Rajiv Ranjan, BigDataSDNSim: A Simulator for Analyzing Big Data Applications in Software-Defined Cloud Data Centers, Software: Practice and Experience (SPE), Volume 51, No. 5, Pages: 893-920, ISSN: 0038-0644, Wiley Press, New York, USA, May 2021.

42. Xindong You, Tian Sun, Sun Dawei, Xunyun Liu, Xueqiang Lv, and Rajkumar Buyya, K-ear: Extracting Data Access Periodic Characteristics for Energy-aware Data Clustering and Storing in Cloud Storage Systems, Concurrency and Computation: Practice and Experience (CCPE), Volume 33, No. 9, Pages: 1-30, ISSN: 1532-0626, Wiley Press, New York, USA, May 2021.

43. H M Dipu Kabir, Abbas Khosravi, Subrota Kumar Mondal, Saeid Nahavandi, Mohammad Mustaneer Rahman, and Rajkumar Buyya, Uncertainty-aware Decisions in Cloud Computing: Foundations and Future Directions, ACM Computing Surveys, Volume 54, No. 4, Article No. 74, Pages: 1-30, ISSN: 0360-0300, ACM Press, New York, USA, May 2021.

44. M.S. Roopa, Rajkumar Buyya, K.R. Venugopal, S.S. Iyengar, and L.M. Patnaik, DRCM: Dynamic Relationship Creation and Management in Social Internet of Things, International Journal of Intelligent Internet of Things Computing, Volume 1, Number 3, Pages: 200-229, ISSN: 2631-7060, Inderscience Publishers, Geneva, Switzerland, May 2021.

45. TianZhang He, Adel Nadjaran Toosi, and Rajkumar Buyya, SLA-Aware Multiple Migration Planning and Scheduling in SDN-NFV-enabled Clouds, Journal of Systems and Software (JSS), Volume 176, Pages: 1-19, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, June 2021.

46. Sadoon Azizi, Mohammad Shojafar, Jemal Abawajy, and Rajkumar Buyya, GRVMP: A Greedy Randomized Algorithm for Virtual Machine Placement in Cloud Data Centers, IEEE Systems Journal, Volume 15, Number 2, Pages: 2571-2582, ISSN: 1932-8184, IEEE Press, New York, USA, June 2021.

47. Wenjuan Li, Jiyi Wu, Jian Cao, Nan Chen, Qifei Zhan, and Rajkumar Buyya, Blockchain-based Trust Management Approaches in Cloud Computing Systems: A Taxonomy,

Review and Future Directions, Journal of Cloud Computing: Advances, Systems and Applications, Volume 10, Pages: 1-34, ISSN: 2192-113X, Springer Nature, UK, June 2021.

48. Chhabi Rani Panigrahi, Joy Lal Sarkar, Bibudhendu Pati, Rajkumar Buyya, Prasant Mohapatra, and Abhishek Majumder, Mobile Cloud Computing and Wireless Sensor Networks: A Review, Integration Architecture, and Future Directions, IET Networks, Volume 10, Number 4, Pages: 141-161, ISSN:2047-4962, Wiley Press, UK, July 2021.

49. Safiollah Heidari and Rajkumar Buyya, A Cost-Efficient Auto-Scaling Algorithm for Large-Scale Graph Processing in Public Clouds with Heterogeneous Resources, IEEE Transactions on Software Engineering (TSE), Volume 47, Number 8, Pages: 1729-1741, ISSN: 0098-5589, IEEE Computer Society Press, USA, August 2021.

50. Md. Whaiduzzaman, Md. JuLkar Nayeen Mahi, Alistair Barros, Md. Ibrahim Khalil, Colin Fidge, and Rajkumar Buyya, BFIM: Performance Measurement of a Blockchain based Hierarchical Tree Layered Fog-IoT Microservice Architecture, IEEE Access, Volume 9, Pages: 106655-106674, ISSN: 2169-3536, IEEE Press, New Jersey, USA, August 2021.

51. Philip Kendrick, Thar Baker, Zakaria Maamar, Abir Hussain, Rajkumar Buyya, and Dhiya Al-Jumeily, An Efficient Multi-Cloud Service Composition Using a Distributed Multiagent-Based, Memory-Driven Approach, IEEE Transactions on Sustainable Computing (T-SUSC), Volume 6, Number 3, Pages: 358-369, ISSN: 2377-3782, IEEE Computer Society Press, USA, July-September 2021.

52. Rajendra Kumar Dwivedi, Rakesh Kumar, and Rajkumar Buyya, Secure Healthcare Monitoring Sensor Cloud With Attribute-Based Elliptical Curve Cryptography, International Journal of Cloud Applications and Computing, Volume 11, No. 3, Pages: 1-18, ISSN: 2156-1834, IGI Press, USA, July-September 2021.

53. Md. Razon Hossain, Md Whaiduzzaman, Alistair Barros, Shelia Rahman Tuly, Md. Julkar Nayeen Mahi, Shanto Roy, Colin Fidge, and Rajkumar Buyya, A Scheduling-Based Dynamic Fog Computing Framework for Augmenting Resource Utilization, Simulation Modelling Practice and Theory, Volume 111, Pages: 1-19, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, September 2021.

54. Harvinder Singh, Sanjay Tyagi, Pardeep Kumar, Sukhpal Singh Gill, and Rajkumar Buyya, Metaheuristics for Scheduling of Heterogeneous Tasks in Cloud Computing Environments: Analysis, Performance Evaluation, and Future Directions, Simulation Modelling Practice and Theory, Volume 111, Pages: 1-23, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, September 2021.

55. Ishu Gupta, Rishabh Gupta, Ashutosh Kumar Singh, and Rajkumar Buyya, MLPAM: A Machine Learning and Probabilistic Analysis based Model for Preserving Security and Privacy in Cloud Environment, IEEE Systems Journal, Volume 15, Number 3, Pages: 4248-4259, ISSN: 1932-8184, IEEE Press, New York, USA, September 2021.

56. Dongcheng Zhao, Gang Sun, Long Luo, Hongfang Yu, Victor Chang, and Rajkumar Buyya, Security-SLA-Guaranteed Service Function Chain Deployment in Cloud-Fog Computing Networks, Journal of Cluster Computing, Volume 24, Number 3, Pages: 2479-2494, ISSN: 1386-7857, Springer, Netherlands, September 2021.

57. Prabhakar Krishnan, Subhasri Duttagupta and Rajkumar Buyya, OpenPATH: Application Aware High-Performance Software-Defined Switching Framework, Journal of Network and Computer Applications (JNCA), Volume 193, Pages: 1-35, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, November 2021.

58. Rajendra Kumar Dwivedi, Rakesh Kumar, and Rajkumar Buyya, A Novel Machine Learning-Based Approach for Outlier Detection in Smart Healthcare Sensor Clouds, International Journal of Healthcare Information Systems and Informatics, Volume 16, No. 4, Pages: 1-26, ISSN: 1555-3396, IGI Press, USA, Oct.-Dec. 2021.

59. Ayaz Ali Khan, Muhammad Zakarya, Rajkumar Buyya, Rahim Khan, Mukhtaj Khan, Omer Rana, An Energy and Performance Aware Consolidation Technique for Containerized Datacenters, IEEE Transactions on Cloud Computing (TCC), Volume 9, Number 4, Pages: 1305-1322, ISSN: 2168-7161, IEEE Computer Society Press, USA, Oct.-Dec. 2021.

60. Minxian Xu, Adel Nadjaran Toosi, and Rajkumar Buyya, A Self-adaptive Approach for Managing Applications and Harnessing Renewable Energy for Sustainable Cloud Computing, IEEE Transactions on Sustainable Computing (T-SUSC), Volume 6, Number 4, Pages: 544-558, ISSN: 2377-3782, IEEE Computer Society Press, USA, Oct.-Dec. 2021.
61. Anish Poonia, Shreya Ghosh, Akash Ghosh, Shubha Brata Nath, Soumya K Ghosh, and Rajkumar Buyya, CONFRONT: Cloud-Fog-Dew based Monitoring Framework for COVID-19 Management, Internet of Things, Volume 16, Pages: 1-18, ISSN: 2542-6605, Elsevier, Amsterdam, The Netherlands. December 2021.
62. M.S. Roopa, S. Ayesha Siddiq, Rajkumar Buyya, K.R. Venugopal, S.S. Iyengar, L.M. Patnaik, DTCMS: Dynamic Traffic Congestion Management in Social Internet of Vehicles (SIoV), Internet of Things, Volume 16, Pages: 1-18, ISSN: 2542-6605, Elsevier, Amsterdam, The Netherlands. December 2021.

Magazine Papers

63. Linna Ruan, Shaoyong Guo, Xuesong Qiu, Luoming Meng, Shuang Wu, and Rajkumar Buyya, Edge In-network Computing Meets Blockchain: A Multi-domain Heterogeneous Resource Trust Management Architecture, IEEE Network Magazine, Volume 35, Issue 5, Pages: 1-i8, ISSN: 0890-8044, IEEE Press, USA, September/October 2021.

Conference Papers

64. Sakib M. Zobaed, Mohsen Amini Salehi, and Rajkumar Buyya, SAED: Edge-Based Intelligence for Privacy-Preserving Enterprise Search on the Cloud, Proceedings of the 21th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2021, IEEE CS Press, USA), Melbourne, Australia, May 10-13, 2021.
65. Anupama Mampage, Shanika Karunasekera, and Rajkumar Buyya, Deadline-aware Dynamic Resource Management in Serverless Computing Environments, Proceedings of the 21th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2021, IEEE CS Press, USA), Melbourne, Australia, May 10-13, 2021.
66. Siddharth Agarwal, Maria A. Rodriguez, and Rajkumar Buyya, A Reinforcement Learning Approach to Reduce Serverless Function Cold Start Frequency, Proceedings of the 21th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2021, IEEE CS Press, USA), Melbourne, Australia, May 10-13, 2021. **- Best Paper Award (Runner-up)**.
67. Qifan Deng, Mohammad Goudarzi and Rajkumar Buyya, FogBus2: A Lightweight and Distributed Container-based Framework for Integration of IoT-enabled Systems with Edge and Cloud Computing, 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.
68. Mohammad Goudarzi, Marimuthu Palaniswami, and Rajkumar Buyya, A Distributed Application Placement and Migration Management Techniques for Edge and Fog Computing Environments, Proceedings of the 16th Conference on Computer Science and Information Systems (FedCSIS 2021, IEEE Press, USA), Sofia, Bulgaria, September 2-5, 2021.
69. Tahseen Khan, Wenhong Tian, Mustafa R. Kadhim, and Rajkumar Buyya, A Novel Cluster Ensemble based on a Single Clustering Algorithm, Proceedings of the 16th Conference on Computer Science and Information Systems (FedCSIS 2021, IEEE Press, USA), Sofia, Bulgaria, September 2-5, 2021.
70. 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.

71. Wei Li, Dawei Sun, Shang Gao, and Rajkumar Buyya, A Machine Learning-based Elastic Strategy for Operator Parallelism in a Big Data Stream Computing System, Proceedings of the 12th International Conference on Broadband Communications, Networks, and Systems (BROADNETS 2021, Springer, Germany), Melbourne, Australia, October 28-31, 2021.
72. Hanchu Zhang, Dawei Sun, Atul Sajjanhar, and Rajkumar Buyya, A Data Stream Prediction Strategy for Elastic Stream Computing Systems, Proceedings of the 12th International Conference on Broadband Communications, Networks, and Systems (BROADNETS 2021, Springer, Germany), Melbourne, Australia, October 28-31, 2021.
73. Bo Li, Dawei Sun, Vinh Loi Chau, and Rajkumar Buyya, A Topology-Aware Scheduling Strategy for Distributed Stream Computing System, Proceedings of the 12th International Conference on Broadband Communications, Networks, and Systems (BROADNETS 2021, Springer, Germany), Melbourne, Australia, October 28-31, 2021.

5. Invited Presentations and Outreach

By the Lab Director:

Keynote Talks at International Conferences

1. Neoteric Frontiers in Cloud and Edge Computing, Third International Conference on Computational Intelligence, Communications, and Business Analytics (CICBA 2021), Santiniketan, West Bengal, India, January 7-9, 2021.
2. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Computing Science, Communication and Security (COMS2-2021), Ganpat University, Gujrat, India, February 6-7, 2021.
3. Neoteric Frontiers in Cloud and Edge Computing, 13th International Conference on Computer and Automation Engineering (ICCAE 2021), Melbourne, Australia, March 20-22, 2021.
4. Neoteric Frontiers in Cloud and Edge Computing, 14th International Conference on Service Science (ICSS 2021), Xian, China, May 14-16, 2021.
5. Neoteric Frontiers in Cloud and Edge Computing, 3rd International Conference on Big Data Engineering (BDE 2021), Shanghai, China, May 29-31, 2021.
6. Neoteric Frontiers in Cloud and Edge Computing, 33th Edition of International Teletraffic Congress (ITC'33), Avignon, France, Aug. 31-Sep. 3, 2021.
7. Neoteric Frontiers in Cloud and Edge Computing, 16th Conference on Computer Science and Intelligence Systems (FedCSIS 2021), Sofia, Bulgaria, September 2-5, 2021.
8. Neoteric Frontiers in Cloud and Edge Computing, 4th International Conference on Big Data Technologies (ICBDT 2021), Zibo, China, September 24-26, 2021.
9. New Frontiers in Cloud and Edge Computing, International Conference on Innovation and Intelligence for Informatics, Computing, and Technologies (3ICT 2021), Bahrain, September 29-30, 2021.
10. Neoteric Frontiers in Cloud and Edge Computing, IEEE Cloud Summit 2021, New York, USA, Oct. 21- 22, 2021.
11. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Information Systems and Computer Networks (ISCON-2021), Mathura, India, October 22-23, 2021.
12. 2nd International Conference on Intelligent and Cloud Computing (ICICC 2021), Bhubaneswar, India, October 22-23, 2021.
13. Neoteric Frontiers in Cloud and Edge Computing, 10th IEEE International Conference on Cloud Networking (IEEE CloudNet 2021), Nov. 8-10, 2021.
14. Neoteric Frontiers in Cloud and Edge Computing, 3rd International Conference on Artificial Intelligence and Speech Technology (AIST 2021), Delhi, India, Nov. 12-13, 2021.
15. Neoteric Frontiers in Cloud and Edge Computing, 2nd IEEE International Conference on Computational Performance Evaluation (ComPE-2021), Shillong, India, December 1-3, 2021.
16. Neoteric Frontiers in Cloud and Edge Computing, 5th International Conference on Electrical, Electronics, Communication, Computer Technologies and Optimization Techniques (ICEECCOT-2021), Mysore, India, December 10-11, 2021.
17. Neoteric Frontiers in Cloud and Edge Computing, 3rd International Conference on Machine Learning, Advances in Computing, Renewable Energy and Communication (MARC-2021), Delhi, India, December 10-11, 2021.
18. Neoteric Frontiers in Cloud and Edge Computing, 10th International Conference on Networks, Communication and Computing (ICNCC 2021), Beijing, China, December 10-12, 2021.
19. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Modelling Simulation and Optimization (CoMSO 2021), NIT Silchar, Assam, India, Dec. 16-18, 2021.

20. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Advanced Network Technologies and Intelligent Computing (ANTIC 2021), Varanasi, India, Dec. 17-18, 2021.
21. Neoteric Frontiers in Cloud and Edge Computing, International Conference On Cyber Technologies and Emerging Sciences (ICCTES 2021), Bhimtal, Uttarakhand, India, Dec. 17-18, 2021.
22. Neoteric Frontiers in Cloud and Edge Computing, 11th International Advanced Computing Conference (IACC 2021), University of Malta, Malta, Dec.18-19, 2021.
23. Neoteric Frontiers in Cloud and Edge Computing, IEEE International Conference on Edge Computing (IEEE EDGE 2021), Guangzhou, China, Dec. 18-20, 2021.

National Conferences

1. Cloud System Engineering Workshop, Huawei Russia Research Institute, Moscow, Russia, November 25, 2021.
2. AICTE Faculty Development Program on Blockchain Technologies and its Applications, Manipal, India, Dec. 6-10, 2021.
3. Storage Technology Workshop, Huawei Tel Aviv Research Center, Tel Aviv, Israel, Dec. 13-14, 2021.
4. Cloud and Sustainability: Transitioning to a Greener Future Panel, Global Technology Summit (GTS), Delhi, India, Dec. 14-16, 2021.

Seminars - in Cloud Computing area:

1. Neoteric Frontiers in Cloud and Edge Computing, National Webinar on Recent Trends in Social Internet of Things (RTSIoT-2021), The University of Mysore, Mysore, India, Feb 22-26, 2021.
2. New Frontiers in Cloud and Edge Computing, Oxford College of Engineering, Bangalore, India, July 8, 2021.
3. New Frontiers in Cloud and Edge Computing, Osmania University, Hyderabad, India, Sept. 14, 2021.
4. New Frontiers in Cloud and Edge Computing, Thiruvalluvar University, Vellore, India, Sept. 16, 2021.
5. New Frontiers in Cloud and Edge Computing, Shanghai Jiao Tong University (SJTU), Shanghai, China, Sept. 24, 2021.
6. New Frontiers in Cloud and Edge Computing, National Institute of Technology, Sikkim, India, Sept 25, 2021.
7. Neoteric Frontiers in Cloud and Edge Computing, Ahmedabad University, India, October 25, 2021.
8. New Frontiers in Cloud and Edge Computing, Sanjay Ghodawat University, Kolhapur, India, Nov. 12, 2021.

6. Selected Community Services

By the Lab Director:

IEEE Computer Society

1. Advisory Board, IEEE Technical Committee on Scalable Computing

Software: Practice and Experience (Wiley)

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

Journal Editorials
1. 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), 2011-to 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. General Chair, 21th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGrid 2021), May 10-13, 2021, Melbourne, Australia.

Community Information Sources

- Maintained a Grid Computing Information Centre at: http://www.gridcomputing.com, 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: http://www.buyya.com/cluster

By Other Members:

Technical Program Committee Memberships + other Professional Services
   * Noted in their profile pages.

7. Members Profile and Activities

Member Self Profile: Shashikant Ilager

I joined CLOUDS Lab as a PhD student in March 2017 and completed my PhD in 2021. I'm currently a postdoctoral researcher at Vienna University of Technology (TU Wien), Austria from August 2021.

Before joining CLOUDS lab, I received my Master of Technology (M. Tech) in Computer Science from the University of Hyderabad, India in 2016 and Bachelor of Engineering (B.E) from VTU, Karnataka, India in 2013. I also worked for a software company in India for a short period. My PhD thesis completed at CLOUDS Lab on "Machine Learning-based Energy and Thermal Efficient Resource Management Algorithms for Cloud Data Centres" has received "Outstanding PhD Thesis Award" from IEEE Technical Committee on Cloud Computing (IEEE TCCLD) in October 2021.

My recent research directions and updates can be found in the following links:
Website: http://www.shashikantilager.com
        LinkedIn:
https://www.linkedin.com/in/shashikantilager/

Member Self Profile: Tianzhang He

I joined CLOUDS lab in Aug 2017, pursuing my PhD position under the supervision of Prof. Rajkumar Buyya and Dr. Adel Nadjaran Toosi.

Before came to Melbourne, I obtained both my bachelor in 2014 in Computer Science and master degree in Computer System in 2017 at Northeastern University (NEU), China. During my graduate time, my research mainly focused on priority-based task scheduling algorithm and response time analysis in real-time systems.

In my current research, the main topic includes **Software-Defined Networking** (SDN) and **Network Function Virtualization** (NFV) in terms of resource management in Cloud Data Centers to ensure the SLA.

Projects:

[1] He, TianZhang, Adel N. Toosi, and Rajkumar Buyya. "Performance evaluation of live virtual machine migration in SDN-enabled cloud data centers." *Journal of Parallel and Distributed Computing* 131 (2019): 55-68.

We investigated the live VM migration in SDN-enabled cloud data centers from the perspectives of computing resources, network resources and application's QoS. This work can benefit the design of SLA-aware multiple live migration planning and live migration cost prediction that used in various resource scheduling policies, such as dynamic VNF/VM placement, consolidation algorithms, scheduled maintenance, etc.

[2] Son, Jungmin, TianZhang He, and Rajkumar Buyya. "CloudSimSDN-NFV: Modeling and simulation of network function virtualization and service function chaining in edge computing environments." *Software: Practice and Experience* 49.12 (2019): 1748-1764.

As an emerging area, there is an urgency of evaluating and simulating the new algorithm in the NFV-enabled Clouds. Thus, we developed the CloudSimSDN-NFV for modeling and simulation of NFV and SFC in edge computing. The new version of CloudSimSDN supporting the inter-data center topology and auto-scaling mechanism for Service Function Chaining (SFC) composed of Virtual Network Functions (VNFs). https://github.com/Cloudslab/cloudsimsdn

[3] TianZhang He, Adel Nadjaran Toosi, and Rajkumar Buyya, SLA-Aware Multiple Migration Planning and Scheduling in SDN-NFV-enabled Clouds, Journal of Systems and Software (JSS), Volume 176, Pages: 1-19, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, June 2021.

In the cloud data centers, performing multiple live migrations in arbitrary order can lead to service degradation and violates the real-time demands. We proposed a multiple migration planning algorithm by creating concurrent migration groups based on the impact, deadline, and overheads of each single migration task and on-line scheduler starts the migration tasks based on the group priorities and resource dependency between migrations.

Member Self Profile: Mohammad Goudarzi

I joined the CLOUDS Lab at the University of Melbourne in July 2018 as a PhD student and Research Assistant under the supervision of Prof. Rajkumar Buyya and Prof. Marimuthu Palaniswami. Recently, I submitted my PhD thesis in February 2022, and I am currently working as a researcher in CLOUDS Lab.

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

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 distributed container-based framework for resource management in Cloud/Fog/Edge computing environments. The successful implementation and deployment of this framework on Oracle Cloud Infrastructure (OCI) got featured in different venues, such as "*OCI Built and Deployed*", "*OCI Blog Post*", and "*Australian Financial Review (AFR)*". 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 University of Melbourne to talented, high-quality PhD students.

I also worked as the Cyber Chair for 20th and 21st 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), and Machine Learning.

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 for IoT applications. In my PhD research, I'm working on efficient application scheduling policies in Fog computing environments, I specially focus on challenges related to scheduling microservices-based IoT applications within Fog environments. Explored areas include QoS-aware scheduling, reliability-aware scheduling and scalable placement of applications. I also worked on developing *"iFogSim2",* *which extends the well known Edge/Fog simulator* "*iFogsim*" to simulate scheduling algorithms for microservices-based IoT applications.

For more information please refer, linkedin and Google Scholar

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 resource-efficiency 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 mid-size 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.
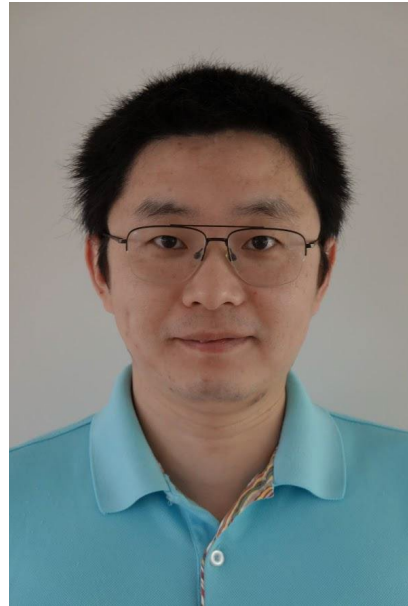
During my industry career, I developed vital interests in resource management and cloud computing. Remembering inspirations gave Prof. Buyya during my master's degree study, I came to him for pursuing a PhD. Currently, my research interest lies in the middle ground of cloud computing, resource management, 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: https://www.linkedin.com/in/jie-zhao-64843765/
Website: https://jiezhao.net/
Email: zhao.j4@student.unimelb.edu.au or j.z@ieee.org

Member Self Profile: Rajeev Muralidhar

I joined the CLOUDS Laboratory in Sep. 2019 as a part time PhD student. I work full time at Amazon Web Services as the Head of IoT/Edge Computing and Robotics Solutions Architecture for Asia/Pacific & Japan.

I have worked in the industry for over 23 years now, and have a background in several technology areas -– semiconductors, energy efficient devices/systems, software-defined networks/protocols/standards, networking and supercomputing/high performance computing. I spent 18 years at Intel. As Principal Engineer in Intel's Client & IoT Architecture Group, I worked on several generations of energy efficiency technologies for industry defining products like the Amazon Echo Show, Google Nexus Player, Google Glass, TAG Hauer smartwatch. Previously, I was at Intel Research Labs working on the foundations of software-defined networking, network processor stacks, and protocols, standards and architectures for quality of service in the internet.

I have a Bachelor of Eng from NIT, Surathkal (India) and Master of Science from Rutgers University, both in Computer Science. I have about 35 US patents (granted) and have published over 25 conference/journal papers. I am also a Senior Member of the IEEE and I am a steering committee member of the IEEE International Conf on High Performance and Big Data Computing.

Here are some of my publications in 2020:

● Rajeev Muralidhar, Renata Borovica-Gajic, Rajkumar Buyya, "Energy Efficient Computing Systems: Architectures, Abstractions and Modeling to Techniques and Standards, Accepted for ACM Computing Survey, Feb 2022.

● Shashikant Ilager, Rajeev Muralidhar, Kotagiri Rammohanrao, and Rajkumar Buyya, A Data-Driven Frequency Scaling Approach for Deadline-aware Energy Efficient Scheduling on Graphics Processing Units (GPUs), 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.

● Rajeev Muralidhar, Renata Borovica-Gajic, and Rajkumar Buyya, Energy Efficient Computing Systems: Architectures, Abstractions and Modeling to Techniques and Standards, ACM Computing Survey

● Shashikant Ilager, Rajeev Muralidhar, and Rajkumar Buyya, Artificial Intelligence (AI)-Centric Management of Resources in Modern Distributed Computing Systems, Proceedings of the IEEE Cloud Summit 2020 (IEEE CS Press, USA), Harrisburg, PA, USA, October 21-22, 2020.

Member Self Profile: Ming Chen

I joined CLOUDS lab as a PhD student at Dec. 2020 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 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 fields include speech recognition, FinTech, Cloud Robotics, etc.

At Melbourne University, I would mainly work in the areas of distributed systems and machine learning. My hobbies include photography and hiking.

Selected publications:

● Ming Chen*, Yanying Lin*, Kejiang Ye, Lujia Wang, Cheng-zhong XU. "PathTracing: Fault Tracing and Prediction for Telecom Core Networks". The 41st IEEE International Conference on Distributed Computing Systems (ICDCS 2021, Under review)

● 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.

● 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]

● 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 ;

● Ming Chen, Lujia Wang, Cheng-zhong Xu，Renfa Li. "A Novel Approach of System Design for Dialect Speech Interaction with NAO robot." IEEE 18th ICAR(International Conference on Advanced Robotics）, Hong Kong , Aug 2017

Self-Profile: Qifan Deng

I obtained my two bachelor's degrees at Beijing Institute of Technology.

I joined the CLOUDS Laboratory in November 2020, as a master majoring in computer science at University of Melbourne.
I am doing 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
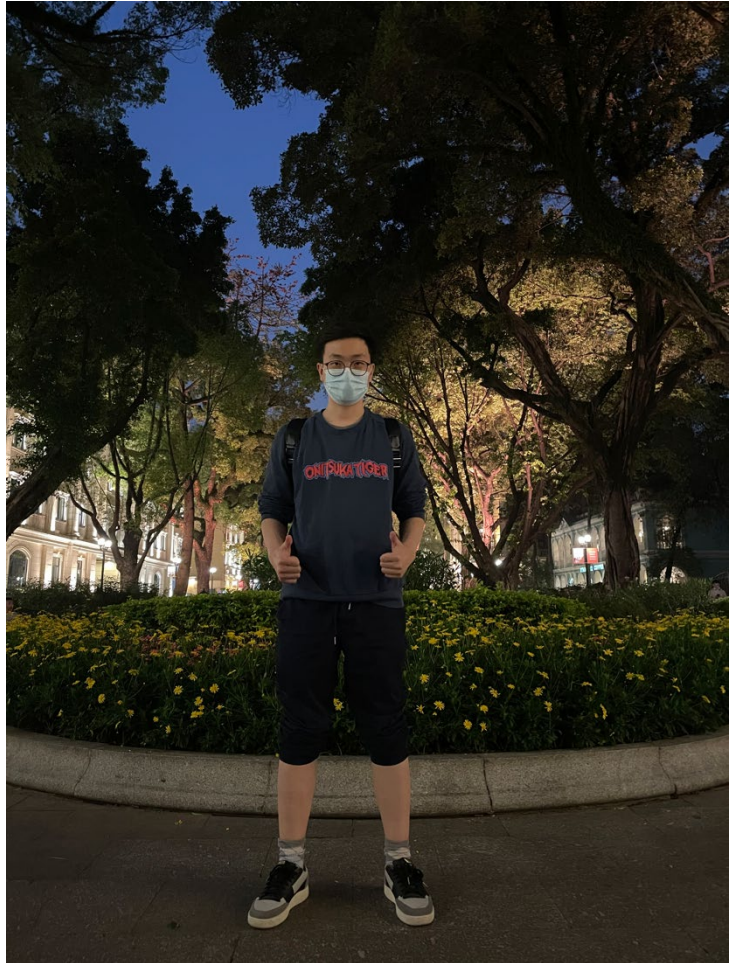
Member self-profile: Siddharth Agarwal

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 received my MSc (Computer Science) from University of Melbourne, Australia, completing mostly from overseas (India) in 2021 and was awarded a Melbourne Research Scholarship for a 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.

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 the PhD under the supervision of Prof. Rajkumar Buyya and Dr Muhammad Usman. My PhD study is fully funded by the Vingroup Scholarship, managed by Vin University, Vietnam.

Before starting my PhD, 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 graduation in 2016, I had 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, by 2020.

My research interests include Serverless computing, Quantum Computing, Edge computing, Federated Learning and Cybersecurity. At CLOUDS Lab, I have been working on the PhD research topic of "Serverless Quantum Cloud Computing", focusing on developing an efficient serverless-based framework for hybrid quantum-classical computation, making quantum cloud computing and quantum software development reliable in the near future.

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

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: 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 first year of my PhD. My research interests include cloud computing, edge computing, and machine learning.

## Member Self Profile: Kalyani Pendyala

I am a recent addition to the CLOUDS LAB crew, joined the team January 2022 as a PhD student.

Pursuing this research course after around 10 years of professional experience working with different Organisations developing and delivering large scale software products.

The practical Industry exposure had incubated some affinity towards large scale Infrastructure open problems, CLOUD optimisation in specific and with the inbuilt passion towards research I have taken up this course with energy efficient CLOUD optimisation as the broad problem area.

Before entering the software world I have completed my Mtech in Artificial Intelligence from University of Hyderabad, India in 2010.

I have started to explore current state of Art and getting myself more proficient with modern cloud architecture in depth and detail.
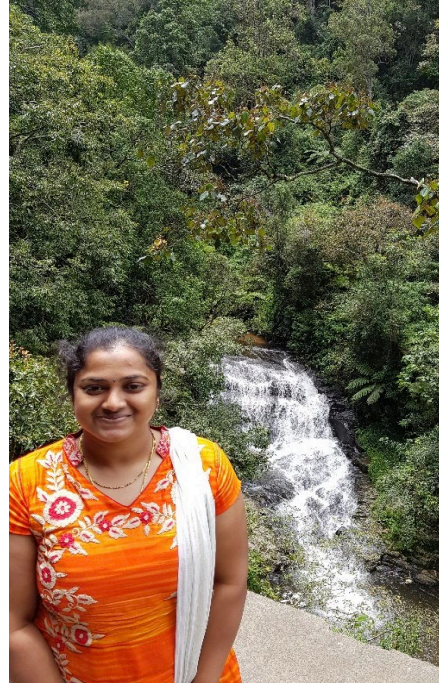
Member Self Profile: Yulun Huang

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.

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

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 2020, we released Aneka 5.0 edition and 2021 updated to latest .NET framework.

Aneka Architecture
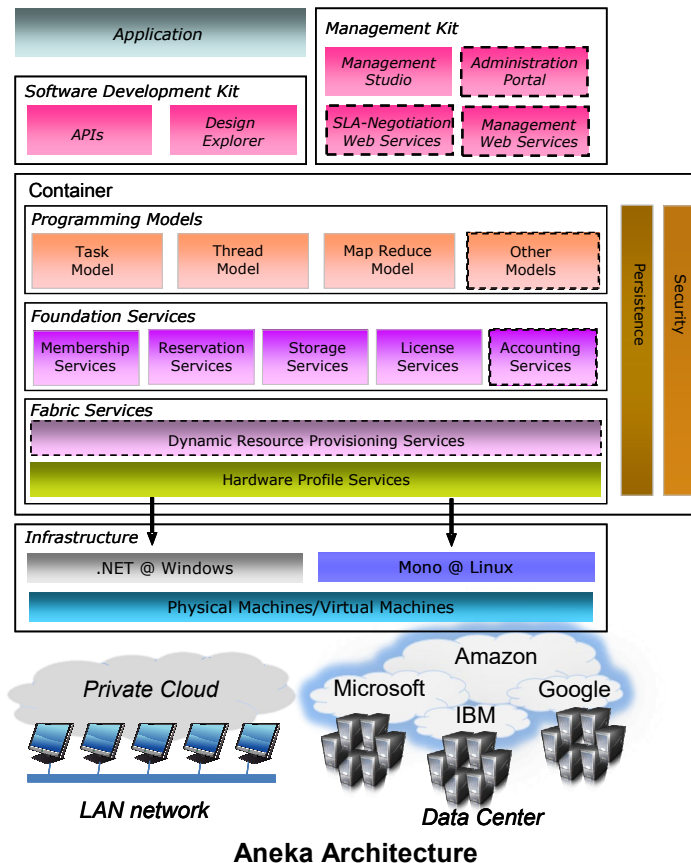
QoS-Oriented Cloud Workflow Engine

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
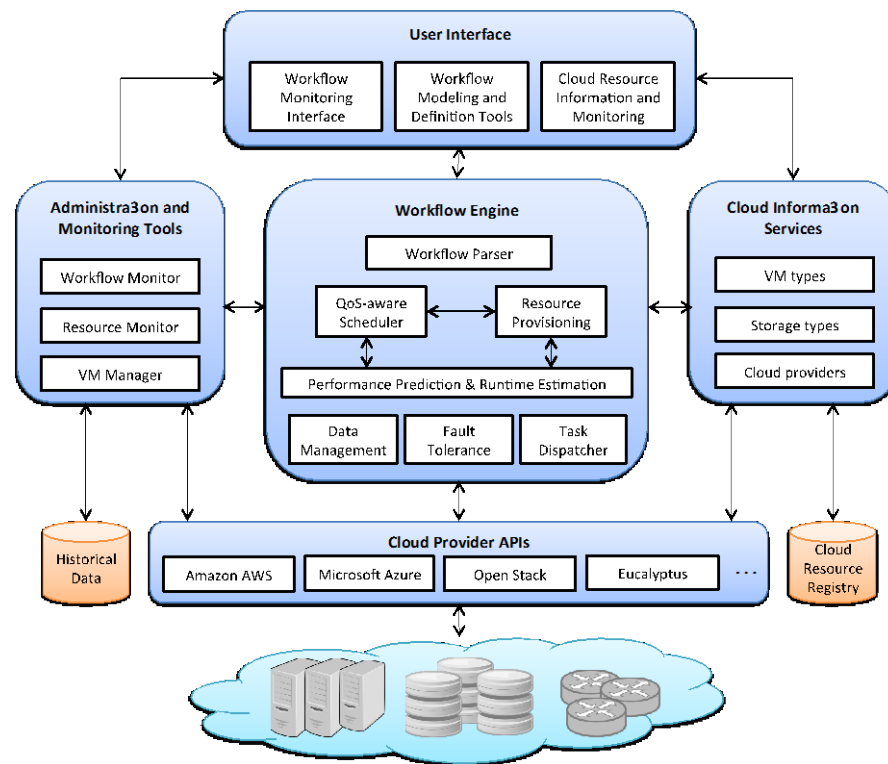- Develop real world demonstrators in various scientific domains such as astronomy.

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

Some References:

- Muhammad Hilman, Maria Rodriguez, and Rajkumar Buyya, Workflow-as-a-Service Cloud Platform and Deployment of Bioinformatics Workflow Applications, 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, Multiple Workflows Scheduling in Multi-tenant Distributed Systems: A Taxonomy and Future Directions, 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, Detecting Performance Anomalies in Scientific Workflows using Hierarchical Temporal Memory, Future Generation Computer Systems, Volume 88, Pages: 624-635, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, November 2018.
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- Suraj Pandey, Letizia Sammut, Rodrigo N. Calheiros, Andrew Melatos, and Rajkumar Buyya, Scalable Deployment of a LIGO Physics Application on Public Clouds: Workflow Engine and Resource Provisioning Techniques, Cloud Computing for Data-Intensive Applications, 3-25pp, Li, Xiaolin, Qiu, Judy (Eds.), ISBN: 978-1-4939-1904-8, Springer, Berlin, Germany, 2014.

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, iBrownout: An Integrated Approach for Managing Energy and Brownout in Container-based Clouds, 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, J-OPT: A Joint Host and Network Optimization Algorithm for Energy-Efficient Workflow Scheduling in Cloud Data Centers, 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, A Data-Driven Frequency Scaling Approach for Deadline-aware Energy Efficient Scheduling on Graphics Processing Units (GPUs), 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, Thermal Prediction for Efficient Energy Management of Clouds using Machine Learning, 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 energy-efficient 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 2021, we worked on 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, CloudSimSDN-NFV: Modeling and Simulation of Network Function Virtualization and Service Function Chaining in Edge Computing Environments, 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, Modelling and Simulation of Fog and Edge Computing Environments using iFogSim Toolkit, 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, Profit-aware Application Placement for Integrated Fog-Cloud Computing Environments, 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, An Application Placement Technique for Concurrent IoT Applications in Edge and Fog Computing Environments, 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.
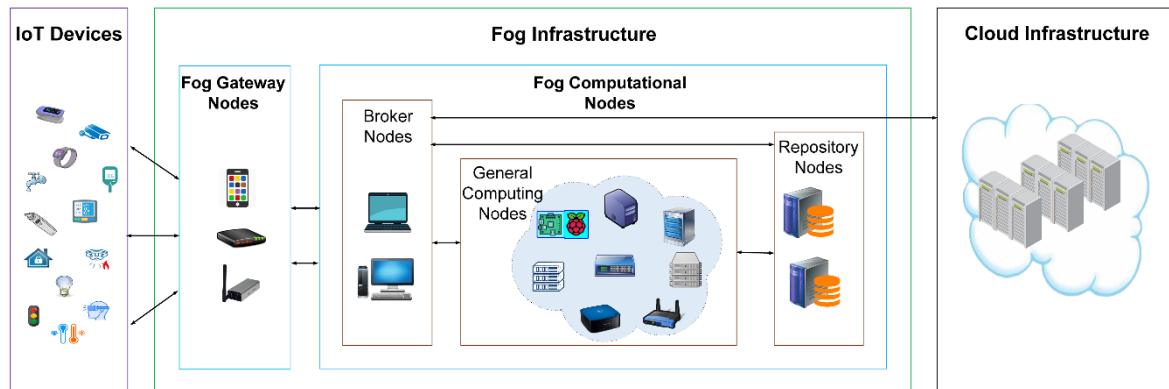
References:

[1] Shreshth Tuli, Redowan Mahmud, Shikhar Tuli, and Rajkumar Buyya, FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing, Journal of Systems and Software (JSS), Volume 154, Pages: 22-36, Elsevier Press, Amsterdam, The Netherlands, August 2019.

[2] Shreshth Tuli, Nipam Basumatary, and Rajkumar Buyya, EdgeLens: Deep Learning based Object Detection in Integrated IoT, Fog and Cloud Computing Environments, 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, FogBus2: A Lightweight and Distributed Container-based Framework for Integration of IoT-enabled Systems with Edge and Cloud Computing, 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.

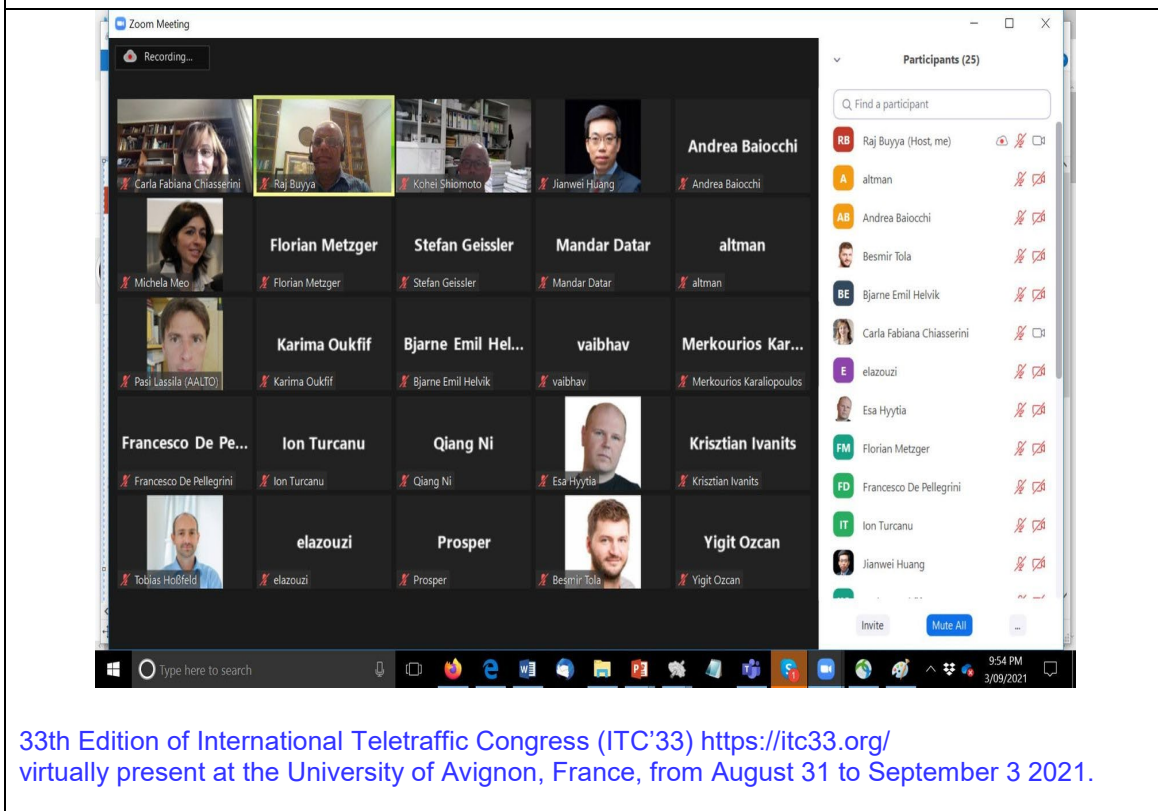# **9**. Moments with Visitors, Colleagues and International Hosts
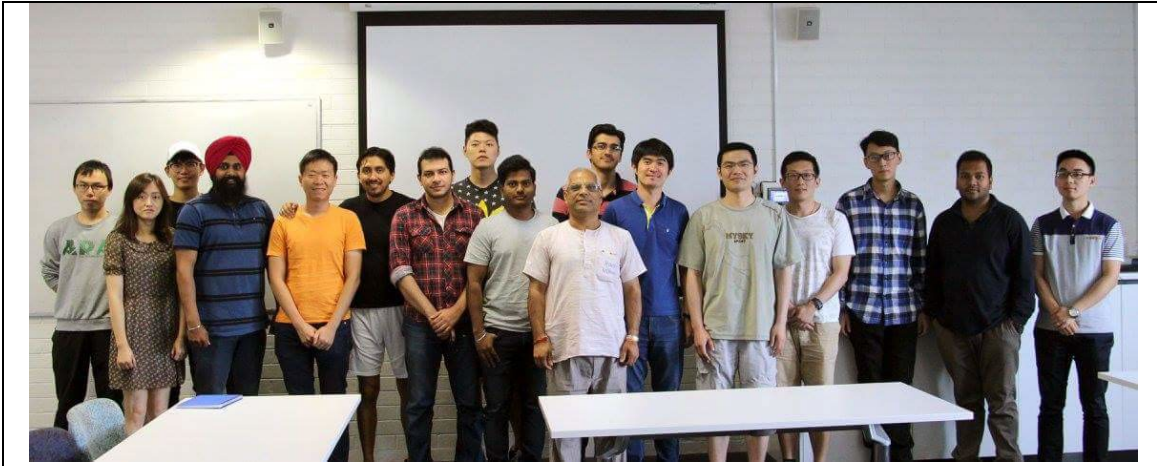
A snap of CLOUDS lab members taken during Jay's PhD completion seminar.

The Australian "Research Review 2021" released today (November 10, 2021).

A snap of "live" interview for Kalkin TV

33th Edition of International Teletraffic Congress (ITC'33) https://itc33.org/
virtually present at the University of Avignon, France, from August 31 to September 3 2021.