

Cloud Computing and Distributed Systems (CLOUDS) Laboratory



Annual Report - 2023



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 **Cloud Computing and Distributed Systems (CLOUDS)** Laboratory at the University of Melbourne, Australia during the academic year 2023, 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 2023 are:



- The Lab successfully attracted ARC Discovery Project along with involvement in two large projects (especially Zero Net Emissions CRC for Agriculture).
- Members of the CLOUDS Lab have authored 40 publications, which include 26 journal papers and 10 conference papers.
- The Lab's flagship Cloudbus Project has released various new modules for 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. We released two new Quantum computing software systems (qFaaS and iQuantum). They have been used by several researchers in academia and industries around the world.
- Members have presented over 40 invited talks that include 14 keynotes delivered at international conferences/events held in Australia, India, China, USA, and France.
- The Lab successfully hosted research activities of over 25 scholars, which include 19 PhD students and 3 Visiting Research Fellows.
- In 2023 alone, our papers have attracted over 10100 citations (ref: Google Scholar). Two of our papers received Best Paper Awards.
- IEEE Technical Committee on Scalable Computing (IEEE TCSC) presented its 2023 "Outstanding PhD Thesis Award" to Dr. Samodha Pallewatta for her PhD thesis.
- We are recognised as the Top Researcher in "Software Systems" field (highest cited in top 20 journals over the past five years), The Australian Research Magazine 2024, The Australian, November 10, 2023.
- A list of the world's top 2% researchers compiled 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 2022 and #2 for career-long citation impact up until the end of 2022 in Distributed Computing area.
- Members of the Lab have led community efforts such as (a) the organisation of conferences (e.g., CCGrid 2023 in India) and (b) Editor-In-Chief of Journal of Software: Practice and Experience, which was established 54+ 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,

A handwritten signature in black ink, appearing to read 'Rajkumar Buyya'.

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
- 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. Zhiyu Wang
- Ms. Duneehsa Fernando
- Ms. Thakshila Imiya Mohottige
- Ms. Niloofar Gholipour, ETS/University of Quebec, Canada
- Mr. Qifan Deng
- Mr. TianYu Qi

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)

- M. Gong; H. Bondell, R. Buyya, and K. Zhang, Causal Knowledge-Empowered Adaptive Federated Learning, Discovery Project, Australian Research Council (ARC), 2024-2026. Amount: \$506,145

Other National Grants

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Industry and Melbourne University Grants

- W. Fei, R. Buyya, and C. Scholes, "Recovering Waste Heat from Data Centres using new Thermal Energy Storage Pile", CIS & IE Research Collaboration Seed Funding Initiative, The University of Melbourne, Australia, 2023. Amount: \$39,707.
 - M. Rodriguez and R. Buyya, "Optimizing Deep Learning Clusters with Transient Capacity using Artificial Intelligence", Meta Platforms, Inc., USA, 2023. Amount: \$72,000
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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	'22	'23
Books/Proceedings	1	1	1	1	5	4	3	5	2	3	2	2	1	2	3	1	2	2	4	8	5	2
Journal Papers	6	1	4	5	6	4	10	13	8	9	15	17	17	17	24	31	43	47	36	42	52	26
Book Chapters	1	0	0	4	4	2	4	11	3	13	3	1	2	3	6	10	1	8	3	9	9	2
Conference Papers	4	7	9	16	15	24	22	27	15	14	12	6	14	21	9	11	15	20	12	10	3	10
Magazine Articles	0	0	1	2	4	2	0	1	2	1	0	5	2	3	1	1	1	0	1	1	0	0
<i>Total</i>	12	9	15	28	34	36	39	57	30	40	32	31	36	46	43	54	62	77	58	70	69	40

Books/Proceedings Edited

1. Rajkumar Buyya, Muhammad Tariq, Valentina Balas, Guojun Wang, Radu Prodan (eds.), [Security and Privacy Issues in Internet of Medical Things](#), 158 pages, ISBN-13: 9780323898720, Elsevier, The Netherlands, March 2023.
2. Rajalakshmi Krishnamurthi, Adarsh Kumar, Sukhpal Singh Gill, and Rajkumar Buyya (eds.), [Serverless Computing: Principles and Paradigms](#), 316 pages, ISBN: 978-3-031-26632-4, Springer, New York, USA, May 2023.

Book Chapters

1. Teena Arora, Venki Balasubramanian, Andrew Stranieri, Mai Shenhan, Rajkumar Buyya, and Sardar M.N. Islam, [Classification of Methods to Reduce Clinical Alarm Signals for Remote Patient Monitoring: A Critical Review](#), Cloud Computing in Medical Imaging, A. El-Baz, J. Suri (eds), 1-22pp, ISBN: 9781003145189, Taylor & Francis Group, UK, March 2023.
2. Rajalakshmi Krishnamurthi, Adarsh Kumar, Sukhpal Singh Gill, and Rajkumar Buyya, [Serverless Computing: New Trends and Research Directions](#), [Serverless Computing: Principles and Paradigms](#), R. Krishnamurthi, A. Kumar, S. Gill, and R. Buyya (eds), 1-13pp, ISBN: 978-3-031-26632-4, Springer, New York, USA, May 2023.

Journal Papers

1. Deepika Saxena, Ashutosh Kumar Singh, Chung-Nan Lee, and Rajkumar Buyya, [A Sustainable and Secure Load Management Model for Green cloud Data Centres](#), Nature Scientific Reports, Pages: 1-22. ISSN: 2045-2322. Springer Nature, London, UK, January 2023.
2. Shreshth Tuli, Sukhpal Singh Gill, Peter Garraghan, Rajkumar Buyya, Giuliano Casale, and Nicholas R. Jennings, [START: Straggler Prediction and Mitigation for Cloud Computing Environments using Encoder LSTM Networks](#), IEEE Transactions on Services Computing (TSC), Volume 16, Number 1, Pages: 615-627, ISSN: 1939-1374, IEEE Computer Society Press, USA, Jan.-Feb. 2023.
3. Wei-Kang Chung, Yun Li, Chin-Heng Ke, Sun-Yuan Hsieh, Albert Zomaya, and Rajkumar Buyya, [Dynamic Parallel Flow Algorithms With Centralized Scheduling for Load Balancing in Cloud Data Center Networks](#), IEEE Transactions on Cloud Computing (TCC), Volume 11, Number 1, Pages: 1050-1064, ISSN: 2168-7161, IEEE Computer Society Press, USA, Jan.-March 2023.
4. Prabhakar Krishnan, Kurunandan Jain, Amjad Aldweesh, P. Prabu and Rajkumar Buyya, [OpenStackDP: A Scalable Network Security Framework for SDN-based OpenStack Cloud Infrastructure](#), Journal of Cloud Computing: Advances, Systems and Applications, Volume 12, Pages: 1-42, ISSN: 2192-113X, Springer Nature, UK, February 2023.
5. Guangyao Zhou, WenHong Tian, Rajkumar Buyya, and Kui Wu, [Growable Genetic Algorithm with Heuristic-based Local Search for Multi-dimensional Resources Scheduling of Cloud Computing](#), Applied Soft Computing, Volume 136, Pages: 1-22, ISSN: 1568-4946, Elsevier Press, Amsterdam, The Netherlands, March 2023.
6. Haiying Shen, Haoyu Wang, Jiechao Gao, and Rajkumar Buyya, [An Instability-Resilient Renewable Energy Allocation System for a Cloud Datacenter](#), IEEE Transactions on

- Parallel and Distributed Systems (TPDS), Volume 34, No. 3, Pages: 1020-1034, ISSN: 1045-9219, IEEE CS Press, USA, March 2023.
7. Rohit Kumar Tiwari, Rakesh Kumar, Gaurav Baranwal, and Rajkumar Buyya, [Decision Making Framework for Heterogeneous QoS Information: An Application to Cloud Service Selection](#), Journal of Ambient Intelligence and Humanized Computing, Volume 14, Number 3, Pages: 2915-2934, ISSN: 1868-5137, Springer Science+Business Media, Berlin, Germany, March 2023.
 8. Ujjwal KC, Jagannath Aryal, K. Shuvo Bakar, James Hilton, and Rajkumar Buyya, [Applying Bayesian Models to Reduce Computational Requirements of Wildfire Sensitivity Analyses](#), Journal of Atmosphere, Volume 14, No. 3, Pages: 1-13, ISSN: 2073-4433, MDPI Press, Basel, Switzerland, March 2023.
 9. Hashim Ali, Muhammad Zakarya, Izaz Ur Rahman, Ayaz Ali Khan, Omer Rana, Lee Gillam, and Rajkumar Buyya, [CoLocateMe: Aggregation-based, Energy, Performance and Cost Aware VM Placement and Consolidation in Heterogeneous IaaS Clouds](#), IEEE Transactions on Services Computing (TSC), Volume 16, Number 2, Pages: 1023-1038, ISSN: 1939-1374, IEEE Computer Society Press, USA, March-April 2023.
 10. Xiaogang Wang, Jian Cao, and Rajkumar Buyya, [Adaptive Cloud Bundle Provisioning and Multi-Workflow Scheduling via Coalition Reinforcement Learning](#), IEEE Transactions on Computers (TC), Volume 72, No. 4, Pages: 1041-1054, ISSN: 0018-9340, IEEE CS Press, Los Alamitos, CA, USA, April 2023.
 11. Guangyao Zhou, Wenhong Tian, and Rajkumar Buyya, [Multi-Search-Routes-based Methods for Minimizing Makespan of Homogeneous and Heterogeneous Resources in Cloud Computing](#), Future Generation Computer Systems (FGCS), Volume 141, Pages: 414-432, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, April 2023.
 12. Mohammad Goudarzi, Marimuthu Palaniswami, and Rajkumar Buyya, [A Distributed Deep Reinforcement Learning Technique for Application Placement in Edge and Fog Computing Environments](#), IEEE Transactions on Mobile Computing (TMC), Volume 22, Number 5, Pages: 2491-2505, ISSN: 1536-1233, IEEE Computer Society Press, USA, May 2023.
 13. Anupama Mampage, Shanika Karunasekera, and Rajkumar Buyya, [Deep Reinforcement Learning for Application Scheduling in Resource-Constrained, Multi-Tenant Serverless Computing Environments](#), Future Generation Computer Systems (FGCS), Volume 143, Pages: 277-292, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, June 2023.
 14. Balawal Shabir, Anis U. Rahman, Asad Waqar Malik, Rajkumar Buyya, and Muazzam A. Khan, [A Federated Multi-agent Deep Reinforcement Learning for Vehicular Fog Computing](#), The Journal of Supercomputing, Volume 79, Number 6, Pages: 6141-6167, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, June 2023.
 15. Shinu M. Rajagopal, M. Supriya, and Rajkumar Buyya, [Resource Provisioning using Meta-heuristic Methods for IoT Microservices with Mobility Management](#), IEEE Access, Volume 11, Pages: 60915-60938, ISSN: 2169-3536, IEEE Press, New Jersey, USA, June 2023.
 16. Mohammad Goudarzi, Marimuthu Palaniswami, and Rajkumar Buyya, [Scheduling IoT Applications in Edge and Fog Computing Environments: A Taxonomy and Future Directions](#), ACM Computing Surveys, Volume 55, No. 7, Article No. 152, Pages: 1-41, ISSN: 0360-0300, ACM Press, New York, USA, July 2023.
 17. Shinu M. Rajagopal, Supriya M., and Rajkumar Buyya, [FedSDM: Federated Learning based Smart Decision Making Module for ECG Data in IoT Integrated Edge-Fog-Cloud Computing Environments](#), Internet of Things: Engineering Cyber Physical Human Systems, Volume 22, Pages: 1-20, ISSN: 2542-6605, Elsevier Press, Amsterdam, The Netherlands, July 2023.

18. Shreshth Tuli, Fatemeh Mirhakimi, Samodha Pallewatta, Syed Zawad, Giuliano Casale, Bahman Javadi, Feng Yan, Rajkumar Buyya, and Nicholas R. Jennings, [AI augmented Edge and Fog Computing: Trends and Challenges](#), Journal of Network and Computer Applications (JNCA), Volume 216, Pages: 1-28, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, July 2023.
19. Somnath Bera, Tanushree Dey, Anwesha Mukherjee, and Rajkumar Buyya, [E-CropReco: A Dew-Edge-based Multi-parametric Crop Recommendation Framework for Internet of Agricultural Things](#), The Journal of Supercomputing, Volume 79, Number 11, Pages: 11965-11999, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, July 2023.
20. Wenhong Tian, Minxian Xu, Wenxia Guo, Kui Wu, Rajkumar Buyya, [Prepartition: Load Balancing Approach for Virtual Machine Reservations in a Cloud Data Center](#), Journal of Computer Science and Technology, Volume 38, No. 4, Pages: 773-792, ISSN: 1000-9000, Springer Nature, Switzerland, July 2023.
21. Satish Kumar, Tao Chen, Rami Bahsoon, and Rajkumar Buyya, [DebtCom: Technical Debt-Aware Service Recomposition in SaaS Cloud](#), IEEE Transactions on Services Computing (TSC), Volume 16, Number 4, Pages: 2545-2558, ISSN: 1939-1374, IEEE Computer Society Press, USA, July-Aug. 2023.
22. Anwesha Mukherjee, Shreya Ghosh, Soumya K. Ghosh, and Rajkumar Buyya, [Mobi-Sense: Mobility-aware Sensor-Fog Paradigm for Mission-Critical Applications using Network coding and Steganography](#), The Journal of Supercomputing, Volume 79, Number 15, Pages: 17495-17518, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, October 2023.
23. Bivasa Ranjan Parida, Amiya Kumar Rath, Bibudhendu Pati, Chhabi Rani Panigrahi, Hitesh Mohapatra, Rajkumar Buyya, [Energy Efficient Virtual Machine Placement in Dynamic Cloud Milieu Using a Hybrid Metaheuristic Technique](#), Computacion y Sistemas, Volume 27, Number 4, Pages: 1147-1155, ISSN: 2007-9737, IPN, Mexico, December 2023.
24. Dawei Sun, Minghui Wu, Zhihong Yang, Atul Sajjanhar, and Rajkumar Buyya, [A Two-Tier Coordinated Load Balancing Strategy over Skewed Data Streams](#), The Journal of Supercomputing, Volume 79, Number 18, Pages: 21028-21056, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, December 2023.
25. Yogesh Sharma, Deval Bhamare, Nishanth Sastry, Bahman Javadi, and Rajkumar Buyya, [SLA Management in Intent-Driven Service Management Systems: A Taxonomy and Future Directions](#), ACM Computing Surveys, Volume 55, No. 13s, Article No. 292, Pages: 1-38, ISSN: 0360-0300, ACM Press, New York, USA, December 2023.
26. Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya, [Placement of Microservices-based IoT Applications in Fog Computing: A Taxonomy and Future Directions](#), ACM Computing Surveys, Volume 55, No. 14s, Article No. 321, Pages: 1-43, ISSN: 0360-0300, ACM Press, New York, USA, December 2023.

Conference Papers

1. Rajkumar Buyya, Satish N. Srirama, Redowan Mahmud, Mohammad Goudarzi, Leila Ismail, and Vassilis Kostako, [Quality of Service \(QoS\)-Driven Edge Computing and Smart Hospitals: A Vision, Architectural Elements, and Future Directions](#), Proceedings of the International Conference on Communication, Electronics and Digital Technology (NICE-DT'23, Springer, Singapore), Delhi, India, February 10-11, 2023. - **Keynote Paper**.

2. Hoa T. Nguyen, Muhammad Usman, and Rajkumar Buyya, [iQuantum: A Case for Modeling and Simulation of Quantum Computing Environments](#), Proceedings of the 2nd IEEE International Conference on Quantum Software (QSW 2023, IEEE CS Press, USA), Chicago, USA, July 2-8, 2023.
3. Tharindu B. Hewage, Shashikant Ilager, Maria A. Rodriguez, Patricia Arroba, and Rajkumar Buyya, [DEMOTS: A Decentralized Task Scheduling Algorithm for Micro-Clouds with Dynamic Power-Budgets](#), Proceedings of the 16th IEEE International Conference on Cloud Computing (IEEE Cloud 2023, IEEE CS Press, USA), Chicago, USA, July 2-8, 2023.
4. Ming Chen, Maria A. Rodriguez, Patricia Arroba, and Rajkumar Buyya, [EN-Beats: A Novel Ensemble Learning-based Method for Multiple Resource Predictions in Cloud](#), Proceedings of the 16th IEEE International Conference on Cloud Computing (IEEE Cloud 2023, IEEE CS Press, USA), Chicago, USA, July 2-8, 2023.
5. Guangyao Zhou, Wenhong Tian, and Rajkumar Buyya, [LPT-One and BFD-One Search Algorithms for Load Balance and Bin-Packing of Cloud Computing](#), Proceedings of the 9th IEEE International Conference on Cloud Computing and Intelligent Systems (CCIS 2023, IEEE Press, USA), Dali, China, August 12-13, 2023.
6. Chenghao Song, Minxian Xu, Kejiang Ye, Huaming Wu, Sukhpal Singh Gill, Rajkumar Buyya, and Chengzhong Xu, [ChainsFormer: A Chain Latency-aware Resource Provisioning Approach for Microservices Cluster](#), Proceedings of the 21st International Conference on Service-Oriented Computing (ICSOC 2023, Springer-Verlag Press, Berlin, Germany), Rome, Italy, Nov. 28-Dec. 1, 2023.
7. □ Shashikant Ilager, Adel N. Toosi, Mayank Raj Jha, Ivona Brandic, Rajkumar Buyya, [A Data-driven Analysis of a Cloud Data Center: Statistical Characterization of Workload, Energy and Temperature](#), Proceedings of the 16th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2023, IEEE CS Press, USA), Messina, Italy, December 4-7, 2023. - **Best Paper Award**.
8. Anupama Mampage and Rajkumar Buyya, [CloudSimSC: A Toolkit for Modeling and Simulation of Serverless Computing Environments](#), Proceedings of the 25th IEEE International Conferences on High Performance Computing and Communications (HPCC 2023, IEEE CS Press, USA), Melbourne, Australia, December 13-15, 2023.
9. Jinwei Liu, Yingjie Lao, Ying Mao, and Rajkumar Buyya, [Sailfish: A Dependency-Aware and Resource Efficient Scheduling for Low Latency in Clouds](#), Proceedings of the 11th IEEE International Conference on Big Data (BigData 2023), Sorrento, Italy, December 15-18, 2023.
10. Nilofar Gholipour, Marcos D. Assuncao, Pranav Agarwal, Julien Gascon-Samson, and Rajkumar Buyya, [TPTO: A Transformer-PPO Based Task Offloading Solution for Edge Computing Environments](#), Proceedings of the 29th IEEE International Conference on Parallel and Distributed Systems (ICPADS 2023), Ocean Flower Island, Hainan, China, December 17-21, 2023.

5. Invited Presentations and Outreach

By the Lab Director:

Keynote Talks at International Conferences

1. New Frontiers in Cloud, Edge and Quantum Computing, International Conference on Communication, Electronics and Digital Technologies (NICE-DT'23), New Delhi, India, February 10-11, 2023.
2. New Frontiers in Cloud, Edge and Quantum Computing, International Conference on Advanced Computing, Machine Learning, Robotics and Internet Technologies (AMRIT 2023), Silchar, India, March 10-11, 2023.
3. New Frontiers in Cloud, Edge and Quantum Computing, International Conference on Electronics, Communication, Computing and Intelligent Information Systems (ICAEICIS 2023), Bangalore, India, April 19-21, 2023.
4. New Frontiers in Cloud, Edge and Quantum Computing, 2nd International Conference on Data Science and Intelligent Applications (ICDSIA-2023), Gandhinagar, Gujarat, India, April 28-29, 2023.
5. New Frontiers in Cloud, Edge and Quantum Computing, International Conference on Internet of Things, Communication, Intelligence and Computing (IC³ 2023), Tumkur, India, May 5-6, 2023.
6. New Frontiers in Cloud, Edge and Quantum Computing, 2nd International Conference on Bigdata Blockchain and Economy Management (ICBBEM 2023), Hangzhou, China, May 19-21, 2023.
7. New Frontiers in Cloud, Edge and Quantum Computing, 7th International Conference on Big Data and Internet of Things (BDIOT 2023), Beijing, China, August 11-13, 2023.
8. New Frontiers in Cloud, Edge and Quantum Computing, International Conference on Academic and Industrial Innovations in Engineering (ICAIIE 2023), Surat, India, August 12-13, 2023.
9. New Frontiers in Cloud, Edge and Quantum Computing, 2023 Asia Conference on Artificial Intelligence, Machine Learning and Robotics (AIMLR 2023), Bangkok, Thailand, September 15-17, 2023.
10. New Frontiers in Cloud, Edge and Quantum Computing, 4th International Conference On Computational Intelligence (ICCI 2023), Surat, India, November 4-5, 2023.
11. New Frontiers in Cloud, Edge and Quantum Computing, 33rd International Telecommunication Networks and Application Conference (ITNAC 2023), Melbourne, Australia, November 29- December 1, 2023.
12. New Frontiers in Cloud, Edge and Quantum Computing, 3rd International Conference on Computers and Automation (CompAuto 2023), Paris, France, December 7-9, 2023.
13. New Frontiers in Cloud, Edge and Quantum Computing, 3rd International Conference on Advanced Network Technologies and Intelligent Computing (ANTIC 2023), Varanasi, India, Dec. 20-22, 2023.
14. New Frontiers in Cloud, Edge and Quantum Computing, 3rd International Conference on Computational Modeling, Simulation and Data Analysis (CMSDA 2023), Sanya, China, December 22-24, 2023.

National Conferences

1. -

Seminars - in Cloud Computing area:

1. New Frontiers in Cloud, Edge, and Quantum Computing, Basaveshwar Engineering College, Bagalkot, India, January 2, 2023.
2. New Frontiers in Cloud, Edge, and Quantum Computing, PDA College of Engineering, Kalaburagi, India, January 4, 2023.

3. New Frontiers in Cloud, Edge, and Quantum Computing, Sharnbasva University, Kalaburagi, India, January 5, 2023.
4. New Frontiers in Cloud, Edge, and Quantum Computing, VTU Regional Campus Kalaburagi, India, January 5, 2023.
5. New Frontiers in Cloud, Edge, and Quantum Computing, GND Engineering College, Bidar, India, January 6, 2023.
6. New Frontiers in Cloud, Edge, and Quantum Computing, Lingaraj Appa Engineering College, Bidar, India, January 6, 2023.
7. New Frontiers in Cloud, Edge, and Quantum Computing, IEEE Hyderabad Section, Hyderabad, India, January 9, 2023.
8. Role of Timely Research and Innovation: A Perspective on Impact and Citation, The University of Hyderabad, Hyderabad, India, January 10, 2023.
9. New Frontiers in Cloud, Edge, and Quantum Computing, SRM University, Chennai, India, January 11, 2023.
10. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Ahmedabad University, Ahmedabad, India, April 24, 2023.
11. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Pandit Deendayal Energy University, Gandhinagar, India, April 25, 2023.
12. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Gujarat Technological University, Ahmedabad, India, April 26, 2023.
13. Role of Timely Research and Innovation: A Perspective on Impact and Citation, Gujarat Technological University, Ahmedabad, India, April 27, 2023.
14. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Sardar Vallabhbhai National Institute of Technology, Surat, India, April 29, 2023.
15. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, University of Visvesvaraya College of Engineering, Bangalore, India, May 4, 2023.
16. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, University of Electronic Science and Technology of China (UESTC), Chengdu, China, October 11, 2023.
17. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Sichuan University, Chengdu, China, October 16, 2023.
18. Role of Timely Research and Innovation: A Perspective on Impact and Citation, University of Electronic Science and Technology of China (UESTC), Chengdu, China, October 16, 2023.
19. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Chinese Academy of Sciences, Beijing, China, October 18, 2023.
20. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Peking University, Beijing, China, October 19, 2023.
21. Cloud Simulation for Building and Evaluating Solutions for Cost and Energy-Efficient Cloud Computing, China University of Geosciences, Beijing, China, October 19, 2023.
22. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Tsinghua University, Beijing, China, October 20, 2023.
23. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Beijing University of Posts and Telecommunications (BUPT), Beijing, China, October 21, 2023.
24. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Shanghai Jiao Tong University (SJTU), Shanghai, China, October 24, 2023.
25. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Shenzhen Institute of Advanced Technology (SIAT), Shenzhen, China, October 25, 2023.
26. Neoteric Frontiers in Cloud, Edge, and Quantum Computing, Indian Institute of Technology (IIT), Patna, India, December 26, 2023.

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

TBA

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: 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 ([Award](#), [OCI Build and Deployed](#), [OCI Blog Post](#), and [Australian Financial Review \(AFR\)](#)).



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 worked on “[u-DDRL: A QoS-Aware Distributed Deep Reinforcement Learning Technique for Service Offloading in Fog computing Environments](#)” in the context of Smart Transport applications.

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 microservices-based IoT applications within Fog environments.



List of my recent works are as follows:

- 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.
- Shreshth Tuli, Fatemeh Mirhakimi, Samodha Pallewatta, Syed Zawad, Giuliano Casale, Bahman Javadi, Feng Yan, Rajkumar Buyya, and Nicholas R. Jennings, AI augmented Edge and Fog Computing: Trends and Challenges, Journal of Network and Computer Applications (JNCA), Volume 216, Pages: 1-28, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, July 2023.
- Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya, Placement of Microservices-based IoT Applications in Fog Computing: A Taxonomy and Future Directions, ACM Computing Surveys, Volume 55, No. 14s, Article No. 321, Pages: 1-43, ISSN: 0360-0300, ACM Press, New York, USA, December 2023.
- Samodha Pallewatta, Vassilis Kostakos and Rajkumar Buyya, MicroFog: A Framework for Scalable Placement of Microservices-based IoT Applications in Federated Fog Environments, Journal of Systems and Software (JSS), Volume 209, Pages: 1-19, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, March 2024.

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 resource-efficiency of cloud data centres.

My work on:

[Multi-Agent Deep Reinforcement Learning Framework for Renewable Energy-Aware Workflow Scheduling on Distributed Cloud Data Centers](#),

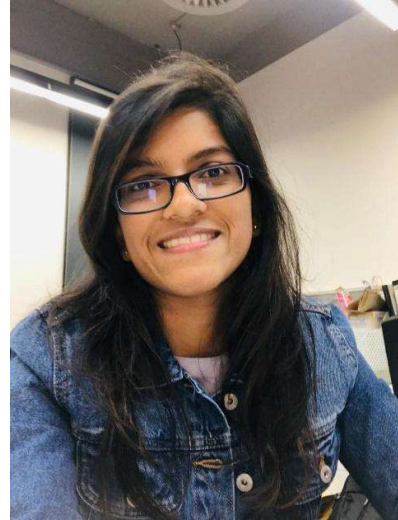
recently accepted for publication in IEEE Transactions on Parallel and Distributed Systems (TPDS).

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.



In 2023, I submitted my PhD thesis 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. My recent work is:

Anupama Mampage, Shanika Karunasekera, and Rajkumar Buyya, Deep Reinforcement Learning for Application Scheduling in Resource-Constrained, Multi-Tenant Serverless Computing Environments, Future Generation Computer Systems (FGCS), Volume 143, Pages: 277-292, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, June 2023.

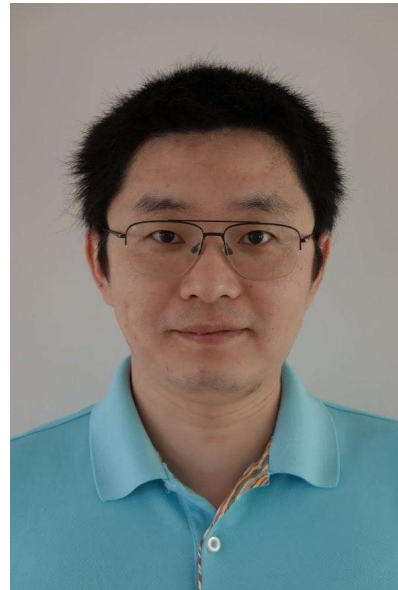
LinkedIn: www.linkedin.com/in/anupama-mampage

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/>

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 related to my PhD:

- Ming Chen, Maria A. Rodriguez, Patricia Arroba, and Rajkumar Buyya, [EN-Beats: A Novel Ensemble Learning-based Method for Multiple Resource Predictions in Cloud](#), Proceedings of the 16th IEEE International Conference on Cloud Computing (IEEE Cloud 2023, IEEE CS Press, USA), Chicago, USA, July 2-8, 2023.

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 have 5+ year teaching experience as a Teaching Assistant and then a university lecturer at the University of Information Technology, VNU-HCM. Besides, I also spent 5 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 Computing, AI, Cloud Computing, and Cybersecurity. At CLOUDS Lab, I have been working on the Ph.D. research topic "*Serverless and Learning-based Resource Orchestration for Quantum Computing in Cloud Environments*," focusing on designing efficient practical and simulation frameworks and techniques to optimize resource orchestration and management for quantum computation tasks in cloud-based environments.



Recent publications

1. **Hoa T. Nguyen**, Muhammad Usman, and Rajkumar Buyya, "QFaaS: A Serverless Function-as-a-Service framework for Quantum computing," *Future Generation Computer Systems*, vol. 154. Elsevier BV, pp. 281–300, May 2024.
2. **Hoa T. Nguyen**, Muhammad Usman, and Rajkumar Buyya, "[iQuantum: A Case for Modeling and Simulation of Quantum Computing Environments](#)", *Proceedings of the 2023 IEEE International Conference on Quantum Software (QSW 2023, IEEE CS Press, USA), Chicago, USA, July 2-8, 2023*.

For more information and networking, please refer to [my LinkedIn](#) and [my website](#).

Member Self Profile: Tharindu B. Hewage

I joined the CLOUDs Lab in 2021 to pursue my doctorate degree, and I am advised by [Prof. Rajkumar Buyya](#), [Dr. Shashikant Ilager](#) (Vienna University Of Technology), and [Dr. Maria A. Rodriguez](#). I come from the beautiful island nation of Sri Lanka, and I am an engineer turned into a researcher. I worked in the industry for over 3.5 years as a senior research and development software engineer for an open-source middleware product, and helped the company to deploy production systems for enterprise.



Currently, I am in my 3rd year of the Ph.D, and my research focus is sustainable cloud datacenters with carbon-aware resource management. I am interested in advancing our understanding of reducing carbon footprints through a software-centric approach, primarily by rethinking cloud computing to treat carbon and energy as first-class resources at the software layer.

My first research contribution, “DEMOTS: A Decentralized Task Scheduling Algorithm for Micro-Clouds with Dynamic Power-Budgets” was published in the proceedings of the IEEE 16th International Conference on Cloud Computing (CLOUD). My recently submitted research work investigates the utilization of real-time workloads for carbon-aware computing through a novel concept that defines renewables for the software orchestration layer.

I keep my personal website updated with the most recent research and professional content. Feel free to take a look and reach out for potential collaborations.

Personal Website: <https://hewage.io/>

Research interests: **Sustainable Cloud Computing, Carbon-aware Distributed Computing**

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 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 a responsible part of all peripheral layers like software application/ architecture and even software development principles.



Member Self Profile: Zhiyu Wang

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

Before starting my PhD, I obtained my Master's degree from the University of Melbourne in 2021. I completed my Master's thesis under the supervision of Professor Rajkumar Buyya.

I am currently in the second year of my PhD. I am now working on applying AI techniques to enhance resource management in edge and cloud computing environments.

My research interests include Edge/Cloud Computing, Artificial Intelligence, the Internet of Things, Distributed Systems, Deep Learning, and Reinforcement Learning.

For more information, please refer to my [Google Scholar](#) page and [LinkedIn](#) profile.



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 : <https://www.linkedin.com/in/duneesha-fernando/>

Google Scholar : <https://scholar.google.com.au/citations?user=azM61FMAAA&hl=en>



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: Tianyu Qi

I joined the CLOUDS lab as a PhD student in June 2023 under the supervision of Dr. Maria Read and Prof. Rajkumar Buyya. I obtained my Bachelor of Engineering in Electronics Engineering from China Agricultural University in 2019 and my Master of Science in Computer Science from the University of Melbourne in 2021. Before joining CLOUDS lab, I worked in Industry as a Java Developer in my country.

In my master's degree, supervised by Dr. Maria Read, my research project topic is resource allocation for Distributed Stream Processing Systems. I am in the first year of my PhD study, whose research is on Serverless Computing for Stream Processing. My research aims to achieve lower latency and higher throughput for stream processing applications.



Publications:

Tianyu Qi and Maria Rodriguez. 2021. A Traffic and Resource Aware Online Storm Scheduler. In Proceedings of the 2021 Australasian Computer Science Week Multiconference (ACSW '21). Association for Computing Machinery, New York, NY, USA, Article 8, 1–10.

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 Erasmus Mundus Euro 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:

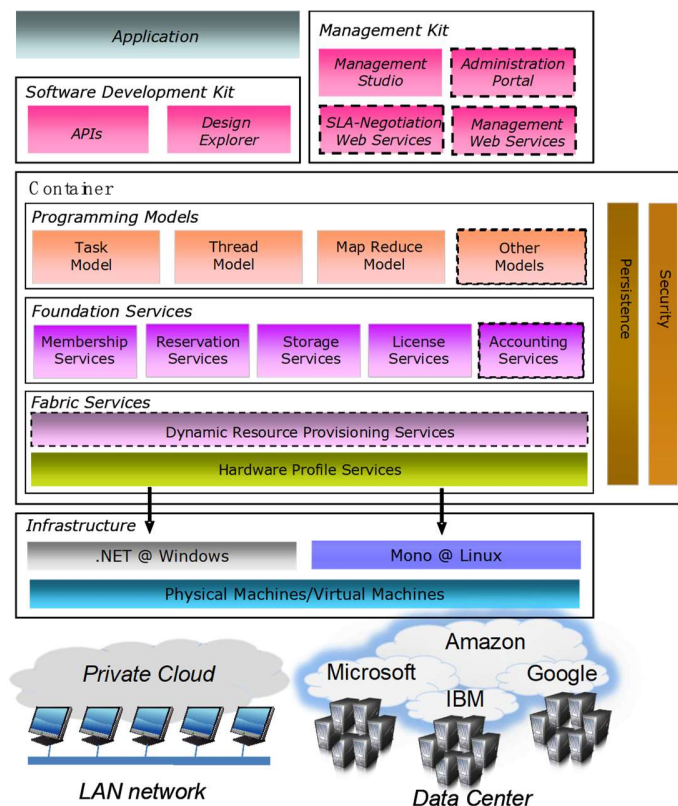
[A Manifesto for Future Generation Cloud Computing: Research Directions for the Next Decade,](#)

Aneka: .NET-based Cloud Computing

Web: <http://www.manjrsoft.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 Manjrsoft, 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.
- Cloudbustering 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.



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.

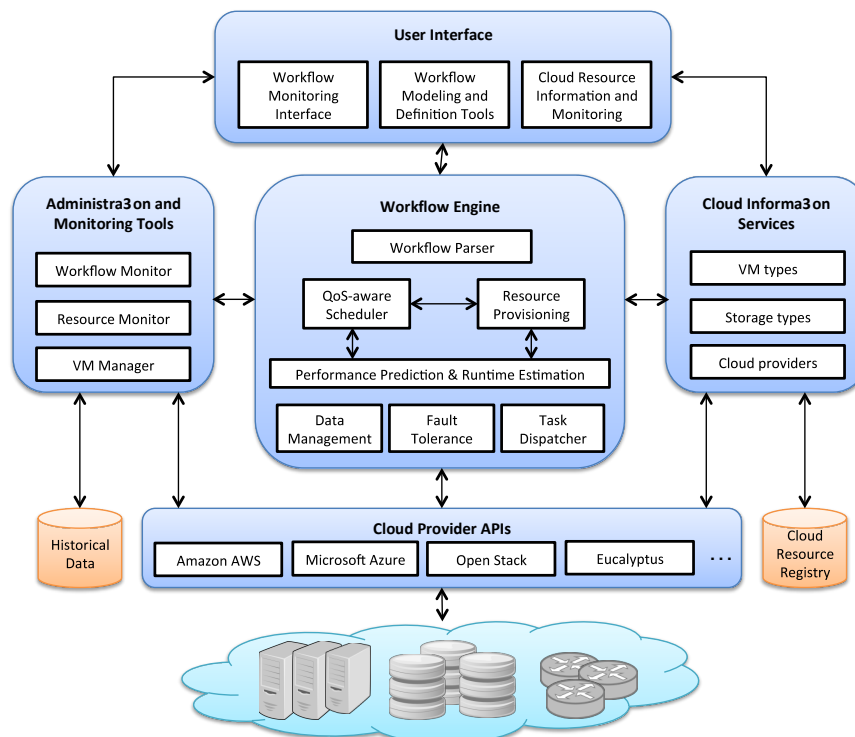


Fig. 1: Architecture of QoS-based workflow management and resource allocation system.

Some References:

- Amanda Jayanetti, Saman Halgamuge, and Rajkumar Buyya, [Multi-Agent Deep Reinforcement Learning Framework for Renewable Energy-Aware Workflow Scheduling on Distributed Cloud Data Centers](#), IEEE Transactions on Parallel and Distributed Systems (TPDS), ISSN: 1045-9219, IEEE CS Press, USA (in press, accepted on 19-Jan-2024).).
- 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.
- Maria A. Rodriguez and Rajkumar Buyya, [Scheduling Dynamic Workloads in Multi-tenant Scientific Workflow as a Service Platforms](#), Future Generation Computer Systems, Volume 79, No. 2, Pages: 739-750, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, February 2018.
- Maria A. Rodriguez and Rajkumar Buyya, Budget-Driven Scheduling of Scientific Workflows in IaaS Clouds with Fine-Grained Billing Periods, ACM Transactions on Autonomous and Adaptive Systems (TAAS), Volume 12, Number 2, Article No.: 5, Pages: 1-22, ISSN: 1556-4665, ACM Press, New York, USA, May 2017.
- 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.
- Shashikant Ilager, Adel N. Toosi, Mayank Raj Jha, Ivona Brandic, Rajkumar Buyya, [A Data-driven Analysis of a Cloud Data Center: Statistical Characterization of Workload, Energy and Temperature](#), Proceedings of the 16th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2023, IEEE CS Press, USA), Messina, Italy, December 4-7, 2023.

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 2022, we release of CloudSim 6.0 alpha.

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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.

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

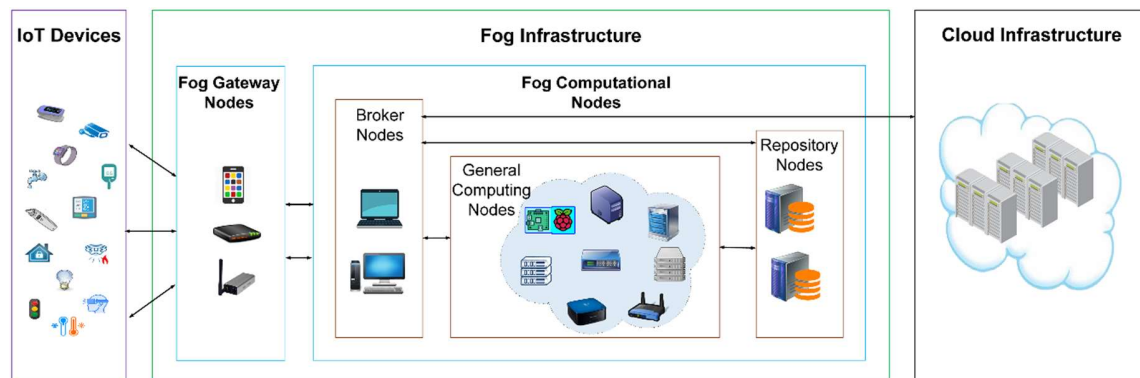
Web: <https://github.com/Cloudslab/FogBus>

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:

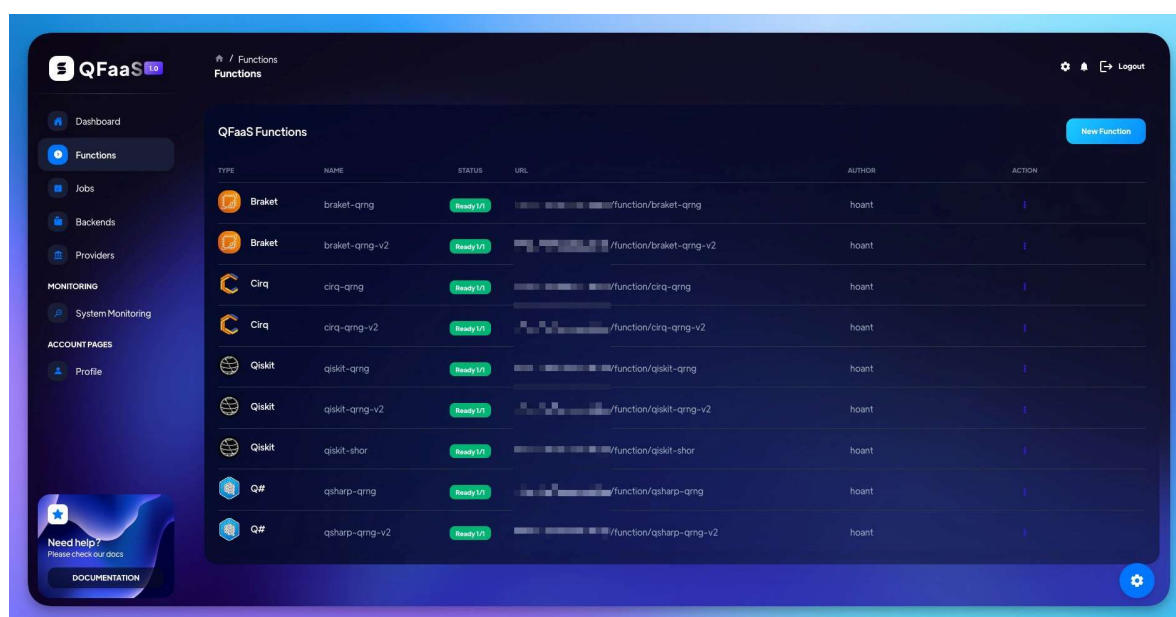
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QFaaS - A Serverless Quantum Function-as-a-Service Framework

QFaaS is a Quantum Function-as-a-Service framework that leverages the advantages of the serverless computing model and state-of-the-art software engineering techniques to advance practical quantum computing in the Noisy Intermediate-Scale Quantum (NISQ) era. Our framework provides essential elements of a serverless quantum system to streamline service-oriented quantum application development in cloud environments, such as combining hybrid quantum-classical computation, automating the backend selection, and adapting Quantum DevOps workflow. QFaaS offers the first full-stack and unified quantum serverless platform by integrating multiple well-known quantum software development kits, quantum simulators, and quantum cloud providers (IBM Quantum and Amazon Braket).

Highlights

- A comprehensive and open-source serverless function-as-a-service framework for quantum computing.
- Support developing quantum functions using 4 popular SDKs, including Qiskit, Q#, Cirq, and Braket.
- Built-in APIs with API gateway to manage system components, quantum functions, jobs, quantum backend and providers.
- Simplify quantum programming and enable hybrid quantum-classical function development.
- Execute quantum functions on both internal quantum simulators and external quantum computers/simulators, such as IBM Quantum and Strangeworks platforms.



- Project's Github: <https://github.com/Cloudslab/qfaas>
- More information: [iQuantum Initiative \(CLOUDS Lab\)](#) – [Publication](#) – [Author's website](#).

Reference

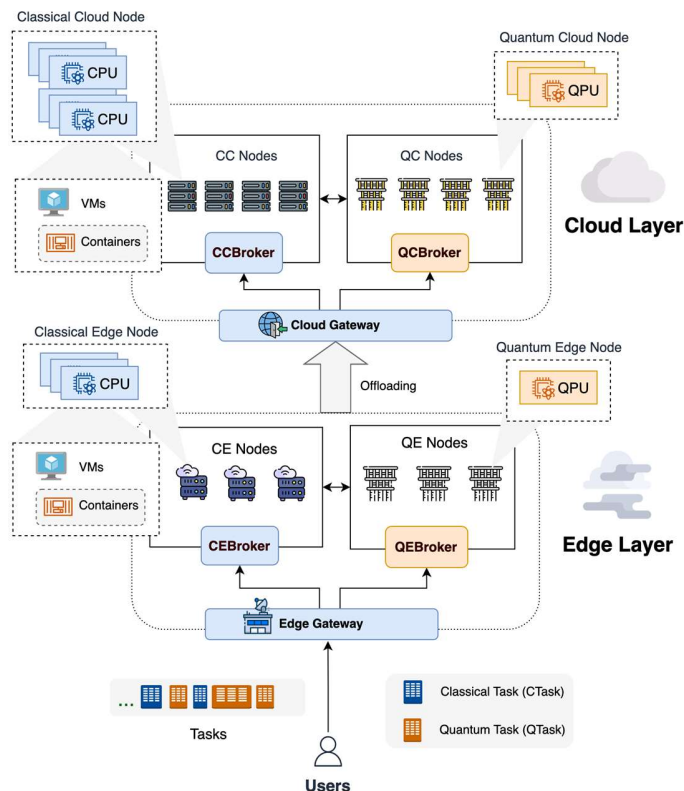
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iQuantum - A Toolkit for Modeling and Simulation of Quantum Computing Environments

As quantum computers become increasingly accessible through cloud services and potentially extend to edge networks in the future, the demand for efficient resource management strategies is paramount to ensure the efficient utilization of quantum computing resources. However, the limitations of employing practical quantum computing resources and the lack of quantum environment modeling toolkits have hindered the design and evaluation of quantum resource management policies. To address this challenge, we propose iQuantum, a lightweight and versatile discrete-event modeling and simulation toolkit (based on CloudSim) for quantum computing environments. iQuantum provides a set of quantum computing entities that can be customized and extended to support a wide range of different hybrid quantum computing environments, supporting research in quantum resource management (e.g., task scheduling, backend selection, hybrid task orchestration), designing and prototyping of quantum computing systems.

Highlights

- Modeling quantum computing entities: QDatacenters, QNode, QPU, QTask, and QBroker.
- Modeling and simulation of quantum resource management, task scheduling, and backend selection policies for quantum computing environments.
- Modeling Hybrid Quantum-Classical Task Orchestration and Offloading in the Cloud-Edge Continuum.
- Importing quantum nodes and workload dataset (from calibration data and QASM files) and exporting simulation results.



▪ Project's Github:

<https://github.com/Cloudslab/iQuantum>

▪ More information: [iQuantum Initiative \(CLOUDS Lab\)](#) – [Publication](#) – [Author's website](#).

Reference

- [1] Hoa T. Nguyen, Muhammad Usman, and Rajkumar Buyya, "iQuantum: A Case for Modeling and Simulation of Quantum Computing Environments," 2023 IEEE International Conference on Quantum Software (QSW), Chicago, IL, USA, 2023, pp. 21-30, doi: [10.1109/QSW59989.2023.00013](https://doi.org/10.1109/QSW59989.2023.00013).
- [2] Hoa T. Nguyen, Muhammad Usman, and Rajkumar Buyya, "iQuantum: A Toolkit for Modeling and Simulation of Quantum Computing Environments", Journal of Software: Practice and Experience, Wiley, 2024, doi: [10.1002/spe.3331](https://doi.org/10.1002/spe.3331) (Extended paper)

9. Moments with Visitors, Colleagues and International Hosts



A snap of CLOUDS lab members (August 2023).



Gujarat Technological University, Ahmedabad, India, April 26, 2023.



International Conference on Data Science and Intelligent Applications (ICDSIA-2023), Gandhinagar, Gujarat, India, April 28-29, 2023.



23rd IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGrid 2023), Bangalore, India, May 1-4, 2023.



Chinese Academy of Science, Beijing, China, Oct 18, 2023.



Visit of Prof. Xian-He Sun, Editor-in-Chief of IEEE TPDS in Dec. 2023



International Conference on Advanced Network Technologies and Intelligent Computing (ANTIC 2023), Varanasi, India, Dec. 20-22, 2023.