

Cloud Computing and Distributed Systems Laboratory and the Cloudbus Project



Annual Report - 2018



School of Computing and Information Systems

Melbourne School of Engineering

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 2018, 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 2018 are:



- The Lab successfully hosted two ARC research projects (Discovery and Linkage Projects) along with two industry funded projects.
- Members of the CLOUDS Lab have authored 62 publications, which include 43 journal papers and 15 conference papers.
- The Lab's flagship Cloudbus Project has released various new modules for Aneka, CloudSim, iFogSim, and Fogbus. The iFogSim building on CloudSim is emerging 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 26 invited talks that include 6 keynotes delivered at international conferences/seminars held in Australia, India, Indonesia, Mauritius, China, Italy, and France.
- The Lab successfully hosted research activities of over 25 scholars, which include 16 PhD students and 4 Research Fellows.
- **"2018 Web of Science Highly Cited Researcher"** recognition from Thomson Reuters for a team member!
- In 2018 alone, our papers have attracted over 10280 citations (ref: Google Scholar) and we hope this trend will continue!
- The Lab housed several (short and long term) international visitors (academics and PhD students) from China, India, Germany, Estonia, Slovenia, and UK.
- Our Lab's spin-off company, Manjrasoft has been recognised as one of the Top 20 Most Trusted Cloud Solution Providers by the Insight Success Magazine.
- Members of the Lab have led community efforts such as (a) the organisation of conferences (e.g., UCC 2018 and BDC 2018 in Switzerland; ICFEC 2018 in USA) 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,

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:

- Dr. Adel Toosi
- Dr. Maria Rodriguez
- Dr. Sukhpal Singh Gill
- Dr. Jungmin Jay Son

PhD Students

- Mr. Safiollah Heidari
- Mr. Xunyun Liu
- Mr. Jaydeep Das, Indian Institute of Technology, Kharagpur
- Mr. Caesar Wu
- Mr. Minxian Xu
- Ms. Sara Kardani Moghaddam
- Mr. Muhammad H. Hilman
- Mr. Redowan Mahmud
- Ms. Imairi Eitiveni
- Mr. Muhammed Tawfiqul
- Mr. Carlos Gomez, University of Birmingham, UK
- Ms. Maria Salama, University of Birmingham, UK
- Mr. Anit Khan, Monash University, Australia
- Mr. Shashikant Ilager
- Mr. TianZhang He
- Mr. Mohammad Goudarzi
- Mr. Zhiheng Zhong

Collaborators

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

International Visitors

- Prof. Satish Narayana Srirama, University of Tartu, Estonia: Jan-Feb 2018.
- Dr Rami Bahsoon, University of Birmingham, Birmingham, UK, Aug 21-Nov 20, 2018.
- Prof. Vlado Stankovski, University of Ljubljana, Slovenia, July 1-Sept 30, 2018.
- Prof. Stefan Voß, University of Hamburg, Germany, Aug 1-15, 2018.
- Dr. Wenjuan Li, Hangzhou Normal University, Hangzhou, China, Dec. 2017-Dec. 2018.
- Shreshth Tuli, Indian Institute of Technology Delhi, India, May-July 2018.

3. Competitive Grants Funded Projects and Programs - Active

Australian Research Council (ARC)

- R. Kotagiri, R. Buyya, C. Leckie, and S. Versteeg, Business goals and analytics driven management of cloud computing based information technology infrastructure, Linkage Project, ARC, 2013-2018. Amount: \$280,000.
- R. Buyya, Algorithms and Software Systems for Management of Software-Defined Clouds, Discovery Project, Australian Research Council (ARC), 2016-2020. Amount: \$410,000.

Other National Grants

- Buyya and M. Assuncao, Algorithms for Placement and Reconfiguration of Data Stream Processing Services for IoT Applications, French National Centre for Scientific Research (CNRS)-Melbourne University Cooperation, The University of Melbourne, Australia, 2017-2018. Amount: \$10,000.

Industry and Melbourne University Grants

- R. Buyya, "Auto-Scaling and Resource Coordination of Network Slices in Software-Defined Clouds", Huawei Innovation Research Program (HIRP), Huawei, China, Sept. 2017-2018. Amount: US\$75,000 (~A\$100,000).
 - R. Buyya, A. Toosi, and M. Sossa, "Cost-Efficient Orchestration of Containers in Clouds", Global Research Outreach (GRO) Program, Samsung, South Korea, Oct. 2017-2018. Amount: US\$120,000 (~A\$150,000).
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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
Books/Proceedings (Authored/Edited)	1	1	1	1	5	4	3	5	2	3	2	2	1	2	3	1	2
Journal Papers	6	1	4	5	6	4	10	13	8	9	15	17	17	17	24	31	43
Book Chapters	1	0	0	4	4	2	4	11	3	13	3	1	2	3	6	10	1
Conference Papers	4	7	9	16	15	24	22	27	15	14	12	6	14	21	9	11	15
Magazine Articles	0	0	1	2	4	2	0	1	2	1	0	5	2	3	1	1	1
<i>Total</i>	12	9	15	28	34	36	39	57	30	40	32	31	36	46	43	54	62

Books/Proceedings Edited

- H. S. Saini, Rishi Sayal, A. Govardhan, and Rajkumar Buyya (editors), Innovations in Computer Science and Engineering: Proceedings of the Fifth International Conference, ISBN 978-981-10-8200-9, Springer, Singapore, May 2018.
- Rajkumar Buyya and Sherly K.K, Proceedings of the 8th International Conference on Advances in Computing and Communications (ICACC-2018, September 13-15, 2018, Kochi, India), Procedia Computer Science, Volume 143, Elsevier Press, Amsterdam, The Netherlands, 2018.

Book Chapters

- Sukhpal Singh Gill and Rajkumar Buyya, Sustainable Cloud Computing Realization for Different Applications: A Manifesto, S. Patnaik, X. Yang, M. Tavana, F. Popentiu-Vladicescu, F. Qiao (eds), Digital Business: Business Algorithms, Cloud Computing and Data Engineering, 95-117pp, ISBN: 978-3-319-93939-1, Springer, Germany, July 2018.

Journal Editorials

- Leonard Heilig, Eduardo Lalla-Ruiz, Stefan Voß, and Rajkumar Buyya, Metaheuristics in cloud computing, Software: Practice and Experience, Volume 48, Number 10, Pages: 1729-1733, ISSN: 0038-0644, Wiley Press, New York, USA, October 2018.

Journal Papers

- Yaser Mansouri, Adel Nadjaran Toosi, and Rajkumar Buyya, Data Storage Management in Cloud Environments: Taxonomy, Survey, and Future Directions, ACM Computing Surveys, Volume 50, No. 6, Article No. 91, Pages: 1-66, ISSN 0360-0300, ACM Press, New York, USA, January 2018.
- Xunyun Liu, Amir Vahid Dastjerdi, Rodrigo N. Calheiros, Chenhao Qu, and Rajkumar Buyya, A Stepwise Auto-Profiling Method for Performance Optimization of Streaming Applications, ACM Transactions on Autonomous and Adaptive Systems (TAAS), Volume 12, Number 4, Article No. 24, Pages: 1-33, ISSN:1556-4665, ACM Press, New York, USA, January 2018.
- Geeta C M, Raghavendra S, Rajkumar Buyya, Venugopal K R, S S Iyengar, and L M Patnaik, Data Auditing and Security in Cloud Computing: Issues, Challenges and Future

- Directions, International Journal of Computer, Volume 28, Number 1, Pages: 8-57, ISSN 2307-4523, January 2018.
8. Li Liu, Shuxian Gu, Dongmei Fu, Miao Zhang, and Rajkumar Buyya, A New Multi-objective Evolutionary Algorithm for Inter-Cloud Service Composition, KSII Transactions on Internet and Information Systems (TIIS), Volume 12, Number 1, Pages: 1-20, ISSN: 1976-7277, KSIT Press, Seoul, Korea, January 2018.
 9. Stelios Sotiriadis, Nik Bessis, Ashiq Anjum, and Rajkumar Buyya, An Inter-Cloud Meta-Scheduling (ICMS) Simulation Framework: Architecture and Evaluation, IEEE Transactions on Services Computing (TSC), Volume 11, Number 1, Pages: 5-19, ISSN: 1939-1374, IEEE Computer Society Press, USA, January/February 2018.
 10. Sukhpal Singh Gill and Rajkumar Buyya, SECURE: Self-Protection Approach in Cloud Resource Management, IEEE Cloud Computing, Volume 5, No. 1, Pages: 60-72, ISSN: 2325-6095, IEEE Computer Society Press, USA, January/February 2018.
 11. 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.
 12. Adel Nadjaran Toosi, Richard Sinnott, and Rajkumar Buyya, Resource Provisioning for Data-intensive Applications with Deadline Constraints on Hybrid Clouds using Aneka, Future Generation Computer Systems, Volume 79, No. 2, Pages: 765-775, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, February 2018.
 13. Blesson Varghese and Rajkumar Buyya, Next Generation Cloud Computing: New Trends and Research Directions, Future Generation Computer Systems, Volume 79, No. 2, Pages: 849-861, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, February 2018.
 14. Marcos Dias de Assuncao, Alexandre Da Silva Veith, and Rajkumar Buyya, Distributed Data Stream Processing and Edge Computing: A Survey on Resource Elasticity and Future Directions, Journal of Network and Computer Applications (JNCA), Volume 103, Pages: 1-17, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, February 1, 2018.
 15. Rajinder Sandhu, Navroop Kaur, Sandeep K. Sood, and Rajkumar Buyya, TDRM: Tensor-based Data Representation and Mining for Healthcare Data in Cloud Computing Environments, The Journal of Supercomputing, Volume 74, Number 2, Pages: 592-614, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, February 2018.
 16. Dawei Sun, Hongbin Yan, Shang Gao, Xunyun Liu, and Rajkumar Buyya, Rethinking Elastic Online Scheduling of Big Data Streaming Applications over High-Velocity Continuous Data Streams, The Journal of Supercomputing, Volume 74, Number 2, Pages: 615-636, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, February 2018.
 17. Bowen Zhou, Amir Vahid Dastjerdi, Rodrigo N. Calheiros, and Rajkumar Buyya, An Online Algorithm for Task Offloading in Heterogeneous Mobile Clouds, ACM Transactions on Internet Technology (TOIT), Volume 18, No. 2, Article 23, Pages: 1-25, ISSN: 1533-5399, ACM Press, New York, USA, March 2018.
 18. Xiangbo Li, Mohsen Amini Salehi, Magdy Bayoumi, Nian-Feng Tzeng, and Rajkumar Buyya, Cost-Efficient and Robust On-Demand Video Transcoding Using Heterogeneous Cloud Services, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 29, No. 3, Pages: 556-571, ISSN: 1045-9219, IEEE CS Press, USA, March 2018.
 19. Marco Netto, Rodrigo N. Calheiros, Eduardo R Rodrigues, Renato L. F. Cunha, and Rajkumar Buyya, HPC Cloud for Scientific and Business Applications: Taxonomy, Vision, and Research Challenges, ACM Computing Surveys, Volume 51, No. 1, Article No. 8, Pages: 1-29, ISSN 0360-0300, ACM Press, New York, USA, April 2018.
 20. Bowen Zhou and Rajkumar Buyya, Augmentation Techniques for Mobile Cloud Computing: A Taxonomy, Survey, and Future Directions, ACM Computing Surveys, Volume 51, No. 1, Article No. 13, Pages: 1-38, ISSN 0360-0300, ACM Press, New York, USA, April 2018.

21. Stelios Sotiriadis, Nik Bessis, and Rajkumar Buyya, Self Managed Virtual Machine Scheduling in Cloud Systems, *Information Sciences: An International Journal*, ISSN: 0020-0255, Volumes 433-434, Pages: 381-400, Elsevier Science, Amsterdam, The Netherlands, April 2018.
22. Sukhpal Singh Gill, Rajkumar Buyya, Inderveer Chana, Maninder Singh, and Ajith Abraham, BULLET: Particle Swarm Optimization based Scheduling Technique for Provisioned Cloud Resources, *Journal of Network and Systems Management*, Volume 26, No. 2, Pages: 361-400, ISSN: 1064-7570, Springer, Berlin, Germany, April 2018.
23. Raghavendra S, Girish S, Geeta C Rajkumar Buyya, Venugopal K R, S S Iyengar, and L M Patnaik, Split keyword fuzzy and synonym search over encrypted cloud data, *Multimedia Tools and Applications: An International Journal*, Volume 77, Number 8, Pages: 10135-10156, ISSN: 1380-7501, Springer, USA, April 2018.
24. Jungmin Son and Rajkumar Buyya, A Taxonomy of Software-Defined Networking (SDN)-Enabled Cloud Computing, *ACM Computing Surveys*, Volume 51, No. 3, Article No. 59, Pages: 1-36, ISSN 0360-0300, ACM Press, New York, USA, June 2018.
25. Safiollah Heidari, Yogesh Simmhan, and Rajkumar Buyya, Scalable Graph Processing Frameworks: A Taxonomy and Open Challenges, *ACM Computing Surveys*, Volume 51, No. 3, Article No. 60, Pages: 1-53, ISSN 0360-0300, ACM Press, New York, USA, June 2018.
26. Rajiv Ranjan, Omer Rana, Surya Nepal, Mazin Yousif, Philip James, Zhenya Wen, Stuart Barr, Paul Watson, Prem Prakash Jayaraman, Dimitrios Georgakopoulos, Massimo Villari, Maria Fazio, Saurabh Garg, Rajkumar Buyya, Lizhe Wang, Albert Y. Zomaya, and Schahram Dustdar, The Next Grand Challenges: Integrating the Internet of Things and Data Science, *IEEE Cloud Computing*, Volume 5, No. 3, Pages: 12-26, ISSN: 2325-6095, IEEE Computer Society Press, USA, May-June 2018.
27. Miao Zhang, Huiqi Li, Li Liu, and Rajkumar Buyya, An Adaptive Multi-Objective Evolutionary Algorithm for Constrained Workflow Scheduling in Clouds, *Distributed and Parallel Databases: An International Journal*, Volume 36, No. 2, Pages: 339-368, ISSN: 0926-8782, Springer, Germany, June 2018.
28. Sukhpal Singh Gill, Inderveer Chana, Maninder Singh, and Rajkumar Buyya, CHOPPER: An Intelligent QoS-aware Autonomic Resource Management Approach for Cloud Computing, *Journal of Cluster Computing*, Volume 21, Number 2, Pages: 1203-1241, ISSN: 1386-7857, Springer, New York, USA, June 2018.
29. Anwesha Mukherjee, Priti Deb, Debashis De, and Rajkumar Buyya, C2OF2N: A Low Power Cooperative Code Offloading Method for Femtolet-based Fog Network, *The Journal of Supercomputing*, Volume 74, Number 6, Pages: 2412-2448, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, June 2018.
30. Wenhong Tian, Majun He, Wenxia Guo, Wenqiang Huang, Xiaoyu Shi, Mingsheng Shang, Adel Nadjaran Toosi, Rajkumar Buyya, On Minimizing Total Energy Consumption in the Scheduling of Virtual Machine Reservations, *Journal of Network and Computer Applications (JNCA)*, Volume 112, Pages: 64-74, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, July 2018.
31. Rustem Dautov, Salvatore Distefano, Dario Bruneo, Francesco Longo, Giovanni Merlino, Antonio Puliato, and Rajkumar Buyya, Metropolitan Intelligent Surveillance Systems for Urban Areas by Harnessing IoT and Edge Computing Paradigms, *Software: Practice and Experience (SPE)*, Volume 48, Issue 8, Pages: 1475-1492, ISSN: 0038-0644, Wiley Press, New York, USA, August 2018.
32. Chenhao Qu, Rodrigo N. Calheiros, and Rajkumar Buyya, Auto-Scaling Web Applications in Clouds: A Taxonomy and Survey, *ACM Computing Surveys*, Volume 51, No. 4, Article No. 73, Pages: 1-33, ISSN 0360-0300, ACM Press, New York, USA, September 2018.
33. Chandrashekar Jatoth, G.R. Gangadharan, Ugo Fiore, and Rajkumar Buyya, QoS-aware Big Service composition using MapReduce based Evolutionary Algorithm with Guided Mutation, *Future Generation Computer Systems*, Volume 86, Pages: 1008-1018, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, September 2018.
34. Santosh Pattar, Rajkumar Buyya, Venugopal K R, S S Iyengar, and L M Patnaik, Searching for the IoT Resources: Fundamentals, Requirements, Comprehensive Review

- and Future Directions, *IEEE Communications Surveys and Tutorials*, Volume 20, Issue 3, Pages: 2101-2132, ISSN: 1553-877X, IEEE Communications Society Press, USA, July-Sept 2018.
35. Ping Kuang, Wenxia Guo, Xiang Xu, Hongjian Li, Wenhong Tian, and Rajkumar Buyya, Analyzing Energy-Efficiency of Two Scheduling Policies in Compute-intensive Applications on Cloud, *IEEE Access*, Volume 6, Pages: 45515-45526, ISSN: 2169-3536, IEEE Press, New Jersey, USA, September 5, 2018.
 36. Thar Baker, Bandar Aldawsari, Muhammad Asim, Hissam Tawfik, Zakaria Maamar, and Rajkumar Buyya, Cloud-SEnergy: A Bin-Packing Based Multi-Cloud Service Broker for Energy Efficient Composition and Execution of Data-intensive Applications, *Journal of Sustainable Computing: Informatics and Systems*, Volume 19, Pages: 242-252, ISSN: 2210-5379, Elsevier Press, Amsterdam, The Netherlands, September 2018.
 37. Peter Garraghan, Renyu Yang, Zhenyu Wen, Alexander Romanovsky, Jie Xu, Rajkumar Buyya, and Rajiv Ranjan, Emergent Failures: Rethinking Cloud Reliability at Scale, *IEEE Cloud Computing*, Volume 5, No. 5, Pages: 12-21, ISSN: 2325-6095, IEEE Computer Society Press, USA, September/October 2018.
 38. Adel Nadjaran Toosi, Jungmin Son, and Rajkumar Buyya, CLOUDS-Pi: A Low-Cost Raspberry-Pi based Micro Data Center for Software-Defined Cloud Computing, *IEEE Cloud Computing*, Volume 5, No. 5, Pages: 81-91, ISSN: 2325-6095, IEEE Computer Society Press, USA, September/October 2018.
 39. Masoom Alam, Naina Emmanuel, Tanveer Khan, Abid Khan, Nadeem Javaid, Kim-Kwang Raymond Choo, and Rajkumar Buyya, Secure Policy Execution using Reusable Garbled Circuit in the Cloud, *Future Generation Computer Systems*, Volume 87, Pages: 488-5015, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, October 2018.
 40. Euripides G.M. Petrakis, Stelios Sotiriadis, Theodoros Soultanopoulos, Pelagia Tsiachri Renta, Rakumar Buyya, and Nik Bessis, Internet of Things as a Service (iTaaS): Challenges and Solutions for Management of Sensor Data on the Cloud and the Fog. *Internet of Things: Engineering Cyber Physical Human Systems*, Volume 3, Pages: 156-174, ISSN 2542-6605, Elsevier Press, Amsterdam, The Netherlands, October 2018.
 41. Li Liu, Qi Fan, and Rajkumar Buyya, A deadline-constrained multi-objective task scheduling algorithm in Mobile Cloud environments, *IEEE Access*, Volume 6, Pages: 2169-3536, ISSN: 2169-3536, IEEE Press, New Jersey, USA, October 12, 2018.
 42. Sun-Yuan Hsieh, Chi-Ting Chen, Chi-Hao Chen, Tzu-Hsiang Yen, Hung-Chang Hsiao, and Rajkumar Buyya, Novel Scheduling Algorithms for Efficient Deployment of MapReduce Applications in Heterogeneous Computing Environments, *IEEE Transactions on Cloud Computing (TCC)*, Volume 6, Number 4, Pages: 1080-1095, ISSN: 2168-7161, IEEE Computer Society Press, USA, October-December 2018.
 43. Jialei Liu, Shangguang Wang, Ao Zhou, Sathish Kumar, Fangchun Yang, and Rajkumar Buyya, Using Proactive Fault-Tolerance Approach to Enhance Cloud Service Reliability, *IEEE Transactions on Cloud Computing (TCC)*, Volume 6, Number 4, Pages: 1191-1202, ISSN: 2168-7161, IEEE Computer Society Press, USA, October-December 2018.
 44. Wenjuan Li, Jian Cao, Jiye Wu, Changqin Huang, and Rajkumar Buyya, A Collaborative Filtering Recommendation Method based on Discrete Quantum-Inspired Shuffled Frog Leaping Algorithms in Social Networks, *Future Generation Computer Systems*, Volume 88, Pages: 262-270, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, November 2018.
 45. 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.
 46. Safiollah Heidari and Rajkumar Buyya, Cost-efficient and Network-aware Dynamic Repartitioning-based Algorithms for Scheduling Large-scale Graphs in Cloud Computing Environments, *Software: Practice and Experience (SPE)*, Volume 48, Issue 12, Pages: 2174-2192, ISSN: 0038-0644, Wiley Press, New York, USA, December 2018.

47. Deepsubhra Guha Roy, Bipasha Mahato, Debashis De, and Rajkumar Buyya, Application-Aware End-to-End Delay and Message Loss Estimation in Internet of Things (IoT)-MQTT-SN Protocols, Future Generation Computer Systems, Volume 89, Pages: 300-316, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, December 2018.

Magazine Papers

48. Rajkumar Buyya and Sukhpal Singh Gill, Sustainable Cloud Computing: Foundations and Future Directions, Business Technology & Digital Transformation Strategies, Cutter Consortium, Vol. 21, no. 6, Pages 1-9, April 2018.

Conference Papers

49. Redowan Mahmud, Fernando Luiz Koch, and Rajkumar Buyya, Cloud-Fog Interoperability in IoT-enabled Healthcare Solutions, Proceedings of the 19th International Conference on Distributed Computing and Networking (ICDCN 2018, ISBN 978-1-4503-6372-3, ACM Press, USA), Varanasi, India, January 4-7, 2018.
50. Md Anit Khan, Andrew P Paplinski, Abdul Malik Khan, Manzur Murshed and Rajkumar Buyya, Exploiting User Provided Information In Dynamic Consolidation of Virtual Machines to Minimize Energy Consumption of Cloud Data Centers, Proceedings of the 3rd IEEE International Conference on Fog and Mobile Edge Computing (FMEC 2018, IEEE Press, New York, USA), Barcelona, Spain, April 23-26, 2018.
51. Salvatore Dipietro, Rajkumar Buyya, and Giuliano Casale, PAX: Partition-Aware Autoscaling for the Cassandra NoSQL Database, Proceedings of the 2018 IEEE/IFIP Network Operations and Management Symposium (NOMS 2018, IEEE Press, New York, USA), Taipei, Taiwan, April 23-27, 2018.
52. Guilherme da Cunha Rodrigues, Rodrigo N. Calheiros, Glederson Lessa dos Santos, Vinicius Tavares Guimaraes, Lisandro Zambenedetti Granville, Liane Tarouco, and Rajkumar Buyya, Unfolding the Mutual Relation Between Timeliness and Scalability in Cloud Monitoring, Proceedings of the 23rd IEEE Symposium on Computers and Communications (IEEE ISCC 2018, IEEE Press, USA), Natal, Brazil, June 25-28, 2018.
53. Imairi Eitiveni, Sherah Kurnia and Rajkumar Buyya, IT-Enabled Capabilities for Sustainable Supply Chain Management: An Affordance Theory Perspective, Proceedings of the 22nd Pacific Asia Conference on Information Systems (PACIS 2018), Yokohama, Japan, June 26-30, 2018.
54. Rajkumar Buyya and Jungmin Son, Software-Defined Multi-Cloud Computing: A Vision, Architectural Elements, and Future Directions, Proceedings of the 18th International Conference on Computational Science and Applications (ICCSA 2018, LNCS, Springer, Germany), Melbourne, Australia, July 2-5, 2018. - Keynote Paper.
55. Devki Nandan Jha, Saurabh Garg, Prem Prakash Jayaraman, Rajkumar Buyya, Zheng Li, and Rajiv Ranjan, A Holistic Evaluation of Docker Containers for Interfering Microservices, Proceedings of the 2018 IEEE International Conference on Services Computing (SCC 2018, IEEE CS Press, USA), San Francisco, USA, July 2-7, 2018.
56. Rajkumar Buyya, Maria A. Rodriguez, Adel Nadjaran Toosi, and Jaeman Park, Cost-Efficient Orchestration of Containers in Clouds: A Vision, Architectural Elements, and Future Directions, Proceedings of the Mathematics, Informatics, Science, and Education International Conference (MISEIC 2018), Surabaya, Indonesia, July 21, 2018. - Keynote Paper.
57. Caesar Wu, Rajkumar Buyya and Kotagiri Ramamohanarao, Cloud Computing Market Segmentation, Proceedings of the 13th International Conference on Software

- Technologies (ICSOF 2018), ISBN: 978-989-758-320-9, Porto, Portugal, July 26-28, 2018.
58. Sukhpal Singh Gill, Rajesh Chand Arya, Gurpreet Singh Wander, and Rajkumar Buyya, Fog-Based Smart Healthcare as a Big Data and Cloud Service for Heart Patients Using IoT, International Conference on Intelligent Data Communication Technologies and Internet of Things (ICICI 2018, ISBN: 978-3-030-03146-6, Springer Nature, Switzerland), Coimbatore, India, August 7-8, 2018.
 59. Carlos Mera-Gómez, Francisco Ramírez, Rami Bahsoon, and Rajkumar Buyya, A Multi-Agent Elasticity Management Based On Multi-Tenant Debt Exchanges, Proceedings of the 12th IEEE International Conference on Self-Adaptive and Self-Organizing Systems (SASO 2018, IEEE CS Press, USA), Trento, Italy, September 3-7, 2018.
 60. Bingfeng Liu, Rajkumar Buyya and Adel Nadjaran Toosi, A Fuzzy-based Auto-scaler for Web Applications in Cloud Computing Environments, Proceedings of the 16th International Conference on Service Oriented Computing (ICSOC 2018, LNCS, Springer-Verlag Press, Berlin, Germany), Hangzhou, Zhejiang, China, November 12-15, 2018.
 61. Adel Nadjaran Toosi and Rajkumar Buyya, Acinonyx: Dynamic Flow Scheduling for Virtual Machine Migration in SDN-enabled Clouds, Proceedings of the 16th IEEE International Symposium on Parallel and Distributed Processing with Applications (ISPA 2018, IEEE CS Press, USA), Melbourne, Australia, December 11-13, 2018.
 62. Satish Kumar, Rami Bahsoon, Tao Chen, Ke Li, and Rajkumar Buyya, Multi-Tenant Cloud Service Composition using Evolutionary Optimization, Proceedings of the 23rd IEEE International Conference on Parallel and Distributed Systems (ICPADS 2018, IEEE CS Press, USA), Singapore, December 11-13, 2018.
 63. Muhammad Hafizhuddin Hilman, Maria A. Rodriguez and Rajkumar Buyya, Task Runtime Prediction in Scientific Workflows Using an Online Incremental Learning Approach, Proceedings of the 11th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2018, IEEE CS Press, USA), Zurich, Switzerland, Dec. 17-20, 2018.
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5. Invited Presentations and Outreach

By the Lab Director:

Keynote Talks at International Conferences

1. New Frontiers in Cloud Computing for Big Data and Internet-of-Things (IoT) Applications, International Conference on Information Systems and Management Science (ISMS 2018), Valletta, Malta, February 22-23, 2018.
2. Vision and Directions for Cyber-Security Program, The Kingdom of Saudi Arabia's R&D International Collaboration Conference, Riyadh, Saudi Arabia, April 23-24, 2018.
3. Cloud Simulation for Building and Evaluating Solutions for Cost and Energy-Efficient Cloud Computing, Huawei Strategy and Technology Workshop (STW 2018), ShenZhen, China, May 15-17, 2018.
4. New Frontiers in Cloud Computing for Big Data and Internet-of-Things (IoT) Applications, International Conference on Computational Science and Applications (ICCSA 2018), Melbourne, Australia, July 2-5, 2018.
5. Recent Advances in Cloud Computing, "Mathematics, Informatics, Science, and Education International Conference (MISEIC 2018), Surabaya, Indonesia, July 21, 2018.
6. New Frontiers in Cloud, Fog and Edge Computing for Internet of Things (IoT) Applications, 3rd International Conference on Advanced Computing and Intelligent Engineering (ICACIE 2018), Bhubaneswar, India, December 22-24, 2018.

National Conferences

1. New Frontiers in Cloud Computing for Big Data and IoT Applications, International Workshop on Cloud and Fog Computing, Kolkata, India, May 4-5, 2018.
2. IoT and Fog/Edge computing for Healthcare, Colloquium on IoT in Industrial and Energy Systems Sustainability, Data61/CSIRO, Melbourne, Australia, Dec. 7, 2018.
3. Blockchain-based Fog/Edge Computing Environment for Internet of Things (IoT) Applications, Workshop on Machine Learning for Cybersecurity (MLC '18), Trivandrum, Kerala, India, Dec. 17-19, 2018.
4. International Workshop on New Frontiers in Cloud and Fog Computing for Big Data and Internet-of-Things (IoT) Applications, Amrita University, Amritapuri, Kerala, India, Dec. 19, 2018.

Seminars - in Cloud Computing area:

1. New Frontiers in Cloud Computing for Big Data and IoT Applications, University of Rome, Tor Vergata Campus, Rome, Italy, February 19, 2018.
2. New Frontiers in Cloud Computing for Big Data and IoT Applications, University of Paris 13, Paris, France, February 26, 2018.
3. New Frontiers in Cloud Computing for Big Data and IoT Applications, INRIA/Ecole Normale Supérieure de Lyon (ENS Lyon), Lyon, France, February 27, 2018.
4. New Frontiers in Cloud Computing for Big Data and IoT Applications, INRIA, Lille, France, February 28, 2018.
5. New Frontiers in Cloud Computing for Big Data and IoT Applications, King Abdulaziz University (KAU), Jeddah, Saudi Arabia, April 25, 2018.
6. New Frontiers in Cloud Computing for Big Data and IoT Applications, Visva-Bharati University, Santiniketan, West Bengal, India, May 1, 2018.
7. New Frontiers in Cloud Computing for Big Data and IoT Applications, Central Mechanical Engineering Research Institute (CMERI), Council of Scientific and Industrial Research (CSIR), Durgapur, West Bengal, India, May 2, 2018.
8. Excellence and Impact of Research and Publications, Beijing University of Posts and Telecommunications (BUPT), Beijing, China, May 7, 2018.

9. Cloud Simulation for Building and Evaluating Solutions for Cost and Energy-Efficient Cloud Computing, University of Science and Technology Beijing (USTB), Beijing, China, May 8, 2018.
10. New Frontiers in Cloud Computing for Big Data and IoT Applications, University of Electronic Science and Technology of China (UESTC), Chengdu, China, May 10, 2018.
11. Excellence and Impact of Research and Publications, University of Electronic Science and Technology of China (UESTC), Chengdu, China, May 11, 2018.
12. New Frontiers in Cloud Computing for Big Data and IoT Applications, Shenzhen University, ShenZhen, China, May 14, 2018.
13. New Trends in Computing for IoT (Internet of Things) Applications, University of Mauritius, Reduit, Mauritius, June 13, 2017.
14. New Frontiers in Cloud Computing for Big Data and IoT Applications, The University of Western Australia (UWA), Perth, Australia, June 18, 2018.
15. New Frontiers in Cloud Computing for Big Data and Internet-of-Things (IoT) Applications, Universitas Negeri Surabaya, Surabaya, Indonesia, July 20, 2018.
16. New Frontiers in Cloud, Fog, and Edge Computing for Big Data and Internet-of-Things (IoT) Applications, Manipal Institute of Technology, Manipal, Karnataka, India, Dec. 31, 2018.

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. Co-Editor in Chief (EIC), 2014-to date.

Journal Editorials

1. Editorial Board Member, Distributed and Parallel Databases: An International Journal of Data Science, Engineering, and Management, 2013-to date.
2. 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.

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.

Technical Program Committee Memberships

1. General Chair, IEEE International Conference on Fog and Edge Computing (ICFEC2018) (with IEEE/ACM CCGrid, May 1-4, 2018), Washington DC, USA.
2. 33rd ACM Symposium On Applied Computing (SAC 2018), April 9 - 13, 2018, Pau, France.
3. 18th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid 2018), May 1-4, 2018, Washington, DC, USA.

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>

Other Members:

Technical Program Committee Memberships + other Professional Services

- * Noted in their profile pages.

7. Members Profile and Activities

Member Self Profile: Adel Nadjaran Toosi

I worked fulltime with the CLOUDS Laboratory up to May 2018 and then joined the Faculty of Information Technology at Monash University after having worked in CLOUDS Lab for almost 8 years. Before joining Monash, I was a PhD student and then a research fellow at the CLOUDS laboratory. I worked on an ARC Discovery Project and Huawei HIRP Project during my research fellowship.



Last year, I have been working on algorithms and software systems for resource management of software-defined clouds. I published 6 journal articles and three conference papers in 2018. I visited Huawei Shanghai with Jungmin Son (Jay) to deliver our project on SDN to the partner team. I also attended the 2018 ISPA (Melbourne) and ICSOC (Hangzhou, China) conferences.

Below are my conference papers published in 2018:

Photo description: The photo is taken in one of the sessions at the ICSOC 2018 conference in Hangzhou, China.

1. Adel Nadjaran Toosi and Rajkumar Buyya, Acinonyx: Dynamic Flow Scheduling for Virtual Machine Migration in SDN-enabled Clouds, Accepted in the 16th IEEE International Symposium on Parallel and Distributed Processing with Applications (ISPA'18), December 11-13, 2018.
2. Bingfeng Liu, Rajkumar Buyya, and Adel Nadjaran Toosi, A Fuzzy-based Auto-scaler for Web Applications in Cloud Computing Environments, In Proceedings of the 16th International Conference on Service-Oriented Computing (ICSOC'18), Nov. 12-15, 2018, Hangzhou, China, pp. 797-811, 2018.
3. Chavit Denninnart, Mohsen Amini Salehi, Adel Nadjaran Toosi, and Xiangbo Li, Leveraging Computational Reuse for Cost- and QoS-Efficient Task Scheduling in Clouds, In Proceedings of the 16th International Conference on Service-Oriented Computing (ICSOC'18), Nov. 12-15, 2018, Hangzhou, China, pp. 828--836, 2018.

My CV and full list of my publications can be found in my homepage at <http://adelnadjarantoosi.info/>

Member Self Profile: Maria Alejandra Rodríguez

I joined the CLOUDS Laboratory in 2012 as a student researching scheduling and resource provisioning algorithms for scientific workflows in cloud environments. I completed my PhD in 2016 and I am now working as a research fellow in the lab.

I have researched different topics as part of my current role. I have investigated container orchestration frameworks and different ways in which the use of resources can be optimized in container-based environments.

I have a bachelor's degree in Computing and Systems Engineering from Los Andes University in Colombia. In 2011 I completed my master's degree at the University of Melbourne (Master of Engineering in Distributed Computing) with first class honors. I have over three years of industry experience gained while working as a software engineer in Colombia and in Tata Consultancy Services in Bangalore, India.

Some of my papers published in 2018 are:

- 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, 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.
- Rajkumar Buyya, Maria A. Rodriguez, Adel Nadjaran Toosi, and Jaeman Park, Cost-Efficient Orchestration of Containers in Clouds: A Vision, Architectural Elements, and Future Directions, Proceedings of the Mathematics, Informatics, Science, and Education International Conference (MISEIC 2018), Surabaya, Indonesia, July 21, 2018. - Keynote Paper.
- Muhammad Hafizhuddin Hilman, Maria A. Rodriguez and Rajkumar Buyya, Task Runtime Prediction in Scientific Workflows Using an Online Incremental Learning Approach, Proceedings of the 11th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2018, IEEE CS Press, USA), Zurich, Switzerland, Dec. 17-20, 2018.



Member Self Profile: Sukhpal Singh Gill

I joined CLOUDS Lab as a Research Fellow in July 2017 and worked on quality of service-based resource management for reliable and sustainable cloud computing and implemented resource management approach using CloudSim.

During 2018, I have been serving as a peer reviewer for many journals including: IEEE Transactions on Parallel and Distributed Computing, Journal of Systems and Software, and IEEE Transactions on Service computing.

I developed an intelligent cloud based and QoS-aware autonomic resource management approach which offers self-configuration of applications and resources, self-healing by handling sudden failures, self-protection against security attacks and self-optimization for maximum resource utilization. I left the Lab in August 2018 to assume a Research Associate position in the Lancaster University, UK.



Below you can find my selected publications related to my research in 2018:

1. **Sukhpal Singh Gill**, Inderveer Chana, Maninder Singh and Rajkumar Buyya, "RADAR: Self-Configuring and Self-Healing in Resource Management for Enhancing Quality of Cloud Services", *Concurrency and Computation: Practice and Experience*, Wiley, vol. 31, pp. 1-27, 2019.
2. **Sukhpal Singh Gill** and Rajkumar Buyya, "A Taxonomy and Future Directions for Sustainable Cloud Computing: 360 Degree View", *ACM Computing Surveys*, vol. 51, no. 5, 33 pages, Article No. 104, 2018.
3. **Sukhpal Singh Gill** and Rajkumar Buyya, "Resource Provisioning based Scheduling Framework for Execution of Heterogeneous and Clustered Workloads in Clouds: From Fundamental to Autonomic Offering", *Journal of Grid Computing*, Springer, 2018.
4. **Sukhpal Singh Gill** and Rajkumar Buyya, "SECURE: Self-Protection Approach in Cloud Resource Management", *Cloud Computing Magazine*, IEEE, vol. 5, no. 1, pp. 60-72, 2018.
5. **Sukhpal Singh Gill** and Rajkumar Buyya, "Failure Management for Reliable Cloud Computing: A Journey, Taxonomy and Future Directions", *Computing in Science and Engineering*, IEEE, 2018.

My CV and full list of my publications can be found in my cyber homepage at:
<http://ssgill.in/>

Member Self Profile: Jungmin Son (Jay)

I was a Research Assistant with CLOUDS Laboratory in 2018 who recently moved to Amazon AWS. I received Ph.D. and Master of Information Technology degrees from the University of Melbourne in 2018 and 2013 respectively. Before moving to Melbourne, I worked in Samsung Electronics for four years as a software engineer after completing B.Eng. at Ajou University, South Korea. I received 2018 IEEE TCSC Outstanding Ph.D Dissertation Award that recognizes an outstanding PhD thesis in the field of the scalable computing with combined theory and practice and in-depth technical contributions.



In my current research, main topic includes how to apply SDN to cloud data centres to ensure SLA and energy efficiency. I investigate VM placement policies that aware network resources and network flow control for providing QoS. This work can help to design cloud data centre in energy-efficient fashion, while guaranteeing SLA. Also, I am interested in network flow management using SDN controller which will provide users efficient network performance while cloud providers can still save costs.

For further details about my current status, research interest, open source projects, and recent publication, please visit my personal website:

- <https://sites.google.com/site/jungminjayson/>

Member Self Profile: Safiollah Heidari

I joined CLOUDS Lab in Jun 2014 at the University of Melbourne as a PhD student under the supervision of Prof. Rajkumar Buyya, Dr. Benjamin Rubinstein and Dr. Rodrigo N. Calheiros.

Previously I have graduated from K. N. Toosi University of Technology, Tehran, Iran, with First Class Honors degree in M.Sc. in Information Technology and I have published a number of papers during my studies. I am

also member of Iran's National Elites Foundation, a prestigious organization for recognize, organize and support Iran's elite national talents.



At CLOUDS Lab, I'm investigating resource provisioning, cost saving, workflow scheduling and network aspects of distributed large-scale graph-processing systems in cloud environments. I developed iGiraph which is a novel Pregel-like graph processing framework for minimizing the monetary costs and computation time of processing on large-scale graph datasets. iGiraph's paper was appeared in CCGrid 2016 conference in Colombia and also won the Google Ph.D. travel prize at University of Melbourne and the runner-up prize for the best student paper from IEEE Victorian Section.

Later, we introduced "Graph Processing-as-a-Service" (GPaaS) as the next popular cloud service where a full-stack of services is proposed for cloud providers by which GPaaS will play a key role in data storage and analytics within organizations. Our paper on entitled "Quality of Service (QoS)-driven Resource Provisioning for Large-scale Graph Processing in Cloud Computing Environments: Graph Processing-as-a-Service (GPaaS)" that have been accepted in *Future Generation Computer Systems (FGCS)* journal in 2019 describes this project in detail.

GraphIoT is the latest framework that I created to facilitate processing Internet of Things (IoT) stream graph data in edge and cloud computing environments.

I recently graduated from The University of Melbourne and am working with various entities from academia and industry.

Member Self Profile: Xunyun Liu

I joined the Clouds lab at University of Melbourne in Sept. 2014, under the supervision of Professor Rajkumar Buyya and Dr. Rodrigo N. Calheiros. In 2015, Dr. Benjamin Rubinstein joined my supervisory committee and I was confirmed as a formal PhD candidate.

I graduated from National University of Defense Technology with a master and a bachelor degree on Computer Science and Technology. My research at that time mainly focused on High Performance Computing (HPC) and compiler optimization. In my Master thesis, I designed a fault-tolerant, sender-based message logging protocol over MPI for fast recovery of faulty scientific applications on the world-renowned TH supercomputer.



After the focus of my PhD shifts to the research of Cloud computing, I started developing interested in stream processing of big data on cloud, including resource provisioning, task scheduling, and fault tolerance issues related to real-time processing. Using Apache Storm as the experiment platform, I have been actively working towards the design and implementation of a SLA-oriented streaming processing platform on cloud.

You are welcome to visit my personal page at <https://xunyunliu.github.io/> for the list of my publications and my thoughts in the field of stream processing.

Member Self Profile: Caesar Wu



I worked for Telstra Corporation over 18 years. Before I joined Telstra, I had worked for many companies across different industries, such as software (artificial intelligence research), naval architecture, electronics, telecommunication, civil engineering, and space industry. In 2015, I started up my Ph.D. research journey under the supervision of Professors: Ramamohanarao Kotagiri and Rajkumar Buyya in Computing and Information Systems (CIS) /School of Engineering/The University of Melbourne.

My research interests include cloud pricing modeling, cloud market segmentation, cloud data center analysis, IT vendor management, cloud resource and capacity planning, data mining, machine learning algorithms, artificial intelligence, IT solution architecture, IT service delivery, and project management.

In Mar 2015, Prof Raj and I completed the book of Cloud Data Center Cost Modeling based on years' experiences across different types of Telstra data centers (Cloud data centers, Next Generation multimedia data centers, enterprise business hosting data centers, and IT data centers).

In 2018, one of my papers was accepted:

- Caesar Wu, Adel N. Toosi, Rajkumar Buyya, and Kotagiri Ramamohanarao, [Hedonic Pricing of Cloud Computing Services](#), IEEE Transactions on Cloud Computing (TCC), ISSN: 2168-7161, IEEE Computer Society Press, USA (in press, accepted on July 15, 2018).

Member Self Profile: Minxian Xu

I joined CLOUDS lab in October 2015, pursuing my PhD position under the supervision of Prof. Rajkumar Buyya at University of Melbourne.

Before coming to Melbourne, I obtained both my bachelor and master degrees at University of Electronic Science and Technology of China (UESTC), both majoring in Software Engineering. During my graduate time, my research mainly focused on resource scheduling and load balancing in Cloud data centers.

During my PhD candidature, I'm still working on resource scheduling, especially investigating energy efficient scheduling for Clouds. I have co-authored several papers by now. If you have interest, please find them below:



1. **Minxian Xu** and Rajkumar Buyya, "Managing Renewable Energy and Carbon Footprint in Multi-cloud Computing Environments", *Future Generation Computer Systems*, 2019 (under review).
2. **Minxian Xu** and Rajkumar Buyya, "BrownoutCon: A Software System based on Brownout and Containers for Energy Efficient Clouds," *The Journal of Systems and Software*, 2019 (under second round review).
3. **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 Parallel and Distributed Systems*, 2018 (under review).
4. **Minxian Xu** and Rajkumar Buyya, "Brownout Approach for Adaptive Management of Resources and Applications in Cloud Computing Systems: A Taxonomy and Future Directions," *ACM Computing Surveys*, ACM Press, New York, USA, Vol 52, Issue 1, pp.1-27, Jan 2019
5. **Minxian Xu**, Adel Nadjaran Toosi, Rajkumar Buyya, *iBrownout: An Integrated Approach for Managing Energy and Brownout in Container-based Clouds*, *IEEE Transactions on Sustainable Computing*, Vol 4, Issue 1, pp.53-66, Jan 2019
6. **Minxian Xu**, Rajkumar Buyya, *Energy Efficient Scheduling of Application Components via Brownout and Approximate Markov Decision Process*, In the *Proceedings of International Conference on Service Oriented Computing (ICSOC)*, pp.206-220, Nov 2017.
7. **Minxian Xu**, Wenhong Tian, Rajkumar Buyya, A Survey on Load Balancing Algorithms for Virtual Machines Placement in Cloud Computing, *Concurrency and Computation: Practice and Experience*, Vol 29, Issue 12, June 2017.
8. **Minxian Xu**, Amir Vahid Dastjerdi, Rajkumar Buyya, *Energy Efficient Scheduling of Cloud Application Components with Brownout*, *IEEE Transactions on Sustainable Computing*, Vol. 1, Issue 2, pp.40-53, Dec 2016.

I have submitted my PhD thesis for examination at November 1st, 2018 and worked as RA at CLOUDS lab. For more information, please visit my personal site: <https://www.minxianxu.info/>

Member Self Profile: Sara Kardani Moghaddam

I joined CLOUDS Lab as a PhD student in September 2015, under the supervision of Professor Ramamohanarao Kotagiri and Professor Rajkumar Buyya in the University of Melbourne. Prior to joining the CLOUDS Lab Group, I received my bachelor's degree with First Class Honors from Shiraz University of Technology and after that I completed a master's degree in information Technology at Sharif University of Technology. Before starting my PhD studies, I also worked for 3 years as a Software Designer and Developer in Iran.



My research interests include data analytics, anomaly detection, Cloud performance management and optimization techniques. Currently, I'm investigating the concepts of performance related anomalies and self-adaptable learning frameworks to find better ways of resource provisioning and auto-scaling in Cloud computing environment.

Member Self Profile: Md. Redowan Mahmud

I completed my BSc from *Department of Computer Science and Engineering, University of Dhaka, Bangladesh* in 2015. Later I was appointed as a lecturer in *Department of Computer Science and Engineering, United International University, Bangladesh*.

I have joined *Cloud Computing and Distributed Systems (CLOUDS) Laboratory, Department of Computing and Information Systems, University of Melbourne, Australia* in February, 2016. Here, I have been

awarded with Melbourne International Research Scholarship (MIRS) and Melbourne International Fee Remission Scholarship (MIFRS) for supporting my studies.



Now, I am in final year of my PhD candidature and exploring resource management and application placement in Fog computing environment. Till date, I have authored 3 book chapter, 1 conference paper and 4 journal papers on Fog computing.

To follow my research activities, please visit

https://www.researchgate.net/profile/Md_Mahmud14 and
<https://scholar.google.com.au/citations?user=rliTpSsAAAAJ&hl=en>

Member Self Profile: Muhammed Tawfiqul Islam

I have joined CLOUDS lab on July, 2016 as a PhD student. I am also a Lecturer at the Department of Computer Science & Engineering, University of Dhaka, Bangladesh and currently I am on a study leave. My research focus in PhD is on “SLA-based cloud resource management for Big Data Applications”.

Prior to finishing my BS and MS studies, I have worked as a software engineer in REVE systems, where I developed VOIP servers in H.323 and SIP protocols. In my MS research, I have worked in collaboration with Internet Society (ISOC) to fight for the cause “Net Neutrality”. I developed end-user applications to detect any blocking/shaping to Internet bandwidth/ services by their Internet Service Providers (ISP) and this project was funded by ISOC Netherlands.



In the year 2018, I have published a book chapter and a journal paper (under review). Here is a list of publications I have finished during the first 2 years of my PhD:

- M. T. Islam, S. Karunasekera and R. Buyya, "dSpark: Deadline-Based Resource Allocation for Big Data Applications in Apache Spark," *2017 IEEE 13th International Conference on e-Science (e-Science)*, Auckland, New Zealand 2017, pp.89-98. doi: 10.1109/eScience.2017.21
- M. T. Islam, S. Srirama and R. Buyya, "Cost-efficient Dynamic Scheduling of Big Data Applications in Apache Spark on Cloud", (Under Review in *ACM Transactions on Computer Systems(TOCS)*)
- M. T. Islam and R. Buyya, "Resource Management and Scheduling for Big Data Applications in Cloud Computing Environments", in *Handbook of Research on Cloud Computing and Big Data Applications in IOT*

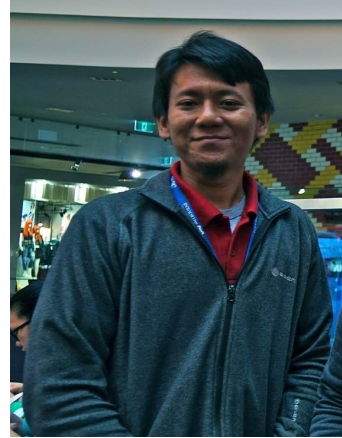
Currently, I am working on the following projects:

- SLA-based Scheduling of Spark jobs in Heterogeneous Hybrid Cloud Environments
- SLA-based Adaptive Resource Management using Deep Reinforcement Learning

Member Self Profile: Muhammad Hafizhuddin Hilman

I joined CLOUDS Lab as a PhD student in January 2016 under the supervision of Prof. Rajkumar Buyya and Dr Amir Vahid Dastjerdi. I am working on Scientific Workflow Management under direct supervision from Research Fellow, Dr Maria A. Rodriguez. My area of interest includes Cloud Computing, Scientific Workflows, Cloud Scheduling, and Cloud Resource Management.

As part of my PhD research, I investigate into the workflow as a service platform. Directly, putting scientific workflow computation into service that provides utility leasing for scientific users. I work on several algorithms on dynamic scheduling and resource provisioning for multiple workflows and modeling the workflow-as-a-service environment. List of my works during PhD are as follows:



1. MH Hilman, MA Rodriguez, R Buyya, "Task-based Budget Distribution Strategies for Scientific Workflows with Coarse-grained Billing Periods in IaaS Clouds", in Proceedings of the 13th IEEE International Conference on e-Science, Auckland 2017.
2. MH Hilman, MA Rodriguez, R Buyya, "Task Runtime Prediction in Scientific Workflows Using an Online Incremental Learning Approach", in Proceedings of the 11th IEEE/ACM International Conference on Utility and Cloud Computing, Zurich 2018.
3. MH Hilman, MA Rodriguez, R Buyya, "Multiple Workflows Scheduling in Multi-tenant Distributed Systems: A Taxonomy and Future Directions", Under Review, ACM Computing Surveys.

I am currently staff-on-leave from Faculty of Computer Science, Universitas Indonesia. I got the scholarship from the Indonesian Government to pursue a PhD at the University of Melbourne. I got my bachelor and master degree from Universitas Indonesia in 2010 and 2012.

For further information, please refer to my LinkedIn page
<https://www.linkedin.com/in/muhammadhilman/>

Member Self Profile: Shashikant Ilager

I joined CLOUDS Lab as a PhD student in March 2017 under the supervision of Prof. Rajkumar Buyya and Prof. Rao Kotagiri at University of Melbourne.

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 studies are supported by Melbourne Research Scholarship (MRS). During my PhD candidature, I am working on resource management techniques to optimize the energy consumption of cooling and computing systems of cloud data centers. Please find the recent published works below:

- Shashikant Ilager, Kotagiri Ramamohanarao, and Rajkumar Buyya, ETAS: Energy and Thermal-Aware Dynamic Virtual Machine Consolidation in Cloud Data Center with Proactive Hotspot Mitigation, Concurrency and Computation: Practice and Experience (CCPE), Volume ??, No. ??, Pages: ??, ISSN: 1532-0626, Wiley Press, New York, USA (in press, accepted on Feb. 6, 2019).
- Shashikant Ilager, Rajeev Wankar, Raghavendra Kune, and Rajkumar Buyya, GPU PaaS Computation Model in Aneka Cloud Computing Environments, Smart Data: State-of-the-Art Perspectives in Computing and Applications, K. Li, Q. Zhang, L. Yang, B. Martino (eds), ISBN-13: 978-1138545588, Chapman & Hall/CRC Press, USA, March 28, 2019. (in press).

For more information, kindly visit the following pages.

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 Master thesis, I analyse response time of OpenMP-based real-time tasks on multi-core systems and design a Benchmark tool called **ompTG** to transform OpenMP programs to the defined OpenMP-based DAG task model.



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. I investigate 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. Furthermore, I am interested in dynamic VNF scheduling in edge computing environment.

Member Self Profile: Mohammad Goudarzi

I joined the CLOUDS Lab in July 2018 at the University of Melbourne as a PhD student under supervision of Prof. Rajkumar Buyya and Prof. Marimuthu Palaniswami.

Previously, I graduated from Iran University of Science and Technology (IUST), Tehran, Iran, with First-Class Honors degree in M.Sc. in Information Technology, where I was awarded as the exceptional talented student as well. In My M.Sc. I worked on Mobile Cloud Computing as my thesis, and I published several research articles.

Moreover, due to my academic achievements, I was awarded to become a member of Iranian National Elites Foundation, a prestigious organization for recognition and support of Iranian national elites, from which I received a prestigious research Grant. Besides, I have three years of experience working as a project manager of Internet of Things (IoT) and Location-Based Services (LBS) solutions in Iran.

At the University of Melbourne, I passed all my PhD courses with the First-Class Honors grade, and also was awarded the Rowden White Scholarship, a prestigious scholarship provided by the University of Melbourne to talented, high quality PhD students.

My research interests include IoT, Fog/Edge Computing, Distributed Systems, Wireless Communication, Optimization, and Data Analytics.

Currently, I am investigating the concepts of Fog computing and IoT, and how we can provide end users with their desired services while guarantee the quality of service and experience.

For further information, you can check my LinkedIn Profile and Google Scholar page.

<https://www.linkedin.com/in/mgoudarzi90/>

https://scholar.google.com/citations?user=a7XqS_QAAAAJ&hl=en



Member Self Profile: Zhiheng Zhong

I started PhD degree in Clouds lab since July 2018, following a Samsung Kubernetes project conducted under the supervision of Prof Rajkumar Buyya and Dr Maria Rodriguez. I received my master's degree in cloud computing from the University of Newcastle, UK and bachelor's degree in Information and Computer Engineering from Nanchang University, China. After completing my master's degree in 2015, I worked in Epam System as a software engineer for 6 months. Then I joined Morgan Stanley and worked as a Java Developer until Feb 2018, mainly responsible for development of trade surveillance application, like detecting market manipulation, ramping, handling high volumes of trading data processing.

My current research project is a prototype system for large-scale container orchestration based on Kubernetes platform. We aim to achieve cost efficiency and energy saving by supporting heterogeneous task configurations for container placements, and utilization optimization through cleaning unhealthy VM instances that are continuously suffering from low resource utilization by a rescheduling mechanism. We plan to build more pricing models and clearer benchmarks of QoS requirements in the future.



Visitor Self Profile: Satish Narayana Srirama



I am a Research Professor and the head of the Mobile & Cloud Lab at the Institute of Computer Science, University of Tartu, Estonia. My research focuses on cloud computing, mobile web services, mobile cloud, Internet of Things, fog computing, migrating scientific computing and enterprise applications to the cloud and large scale data analytics on the cloud. During April - August 2017 and also in Jan 2018, I have visited CLOUDS Lab as part of my sabbatical. During the visit, we have mainly collaborated in mobile cloud and fog computing domains. We have also co-ordinated in defining the manifesto for future generation cloud computing with the research focus at next decade.

Some of the joint publications are mentioned here:

- R. Mahmud, S. N. Srirama, R. Kotagiri, R. Buyya: Quality of Experience (QoE)-aware Placement of Applications in Fog Computing Environments, Journal of Parallel and Distributed Computing, ISSN: 0743-7315, 2018. Elsevier. (In Print)
- C. Chang, S. N. Srirama, R. Buyya: Indie Fog: An Efficient Fog-Computing Infrastructure for the Internet of Things, IEEE Computer, ISSN: 0018-9162, 50(9):92-98, 2017. IEEE. DOI: 10.1109/MC.2017.3571049
- B. Zhou, A. V. Dastjerdi, R. N. Calheiros, S. N. Srirama, R. Buyya: mCloud: A Context-aware Offloading Framework for Heterogeneous Mobile Cloud, IEEE Transactions on Services Computing, ISSN: 1939-1374, 10(5):797-810, 2017. IEEE. DOI: 10.1109/TSC.2015.2511002
- Rajkumar Buyya, Satish Narayana Srirama, Giuliano Casale, Rodrigo Calheiros, Yogesh Simmhan, Blessen Varghese, Erol Gelenbe, Bahman Javadi, Luis Miguel Vaquero, Marco A. S. Netto, Adel Nadjaran Toosi, Maria Alejandra Rodriguez, Ignacio M. Llorente, Sabrina De Capitani di Vimercati, Pierangela Samarati, Dejan Milojicic, Carlos Varela, Rami Bahsoon, Marcos Dias de Assuncao, Omer Rana, Wanlei Zhou, Hai Jin, Wolfgang Gentzsch, Albert Zomaya, and Haiying Shen: A Manifesto for Future Generation Cloud Computing: Research Directions for the Next Decade, ACM Computing Surveys, Volume 51, No. 5, Article No. 105, Pages: 1-38, ISSN 0360-0300, ACM Press, New York, USA, January 2019.

Visitor Self Profile: Mohammadreza Razian

I received B.Sc. in Information Technology with rank 1th from Semnan University, Semnan, Iran in 2012. I received M.Sc. in Information Technology from Department of Computer Engineering, Sharif University of Technology, Tehran, Iran in 2014. During my research in master, I was working on data and computer networks security in Data and Network Security Laboratory (DNSL) of Sharif University of Technology. I was tutor of Computer Workshop and Computer Network lab in Sharif.



By the end of 2014 (I got Ranked 23th among more than 1000 participants in the entrance exam for Ph.D. position, 2014), I started my PhD studies at the Iran University of Science and Technology (IUST), Tehran, Iran, working in the areas of Cloud Computing. My PhD thesis focuses on investigating the methods for QoS-aware Service Composition for Cloud/IoT/Fog environments under uncertainty of QoS values. I joined the CLOUDS Lab in September 2018 as a research visitor at the University of Melbourne under the supervision of Professor Rajkumar Buyya. My research visit was sponsored by Ministry of Science, Research and Technology of Iran to carry part of ongoing Ph.D, and extended by Professor Buyya. Prior to joining the CLOUDS, I had solid experience in the industry, stepping from web development to computer network and web hardening. Furthermore, I was a lecturer in Sharif University of Technology and Semnan University for 1 and 3 years respectively. Generally, my research interests are Cloud Computing, IoT and Fog, Data and Computer Network Security.

For more information and publications, please visit my webpage: <http://mrazian.com>

Visitor Self Profile: Wenjuan Li

My name is Wenjuan Li, I'm an associate professor at Hangzhou Normal University, China. I joined CLOUDS lab in December 2017 as a visiting scholar under the supervision of Prof. Rajkumar Buyya at University of Melbourne.

I also serve as a post doctor at Shanghai Jiao Tong University from October, 2015. I obtained my doctor degree from Zhejiang University, majoring in Computer Science and Technology. My research mainly focused on resource scheduling and service trust in cloud computing environments.

Prof. Rajkumar Buyya is a very kind man, he gives me a lot of valuable advice on my research work. I spent an unforgettable and meaningful year in Melbourne. I submitted four papers during my stay in CLOUDS Lab. If you have interest, please find them below:



- Wenjuan Li, Jian Cao, Jiyi Wu, Changqin Huang, and Rajkumar Buyya. "Research on Collaborative filtering recommendation methods based on Discrete Quantum-Inspired Shuffled Frog Leaping Algorithms in Social Networks." *Future Generation Computer Systems*, Volume 88, Nov. 2018.
- Wenjuan Li, Jian Cao, and Shiyu Qian. "Comprehensive Evaluation of Cloud Services based on Fuzzy Grey Method." *International Journal of Information Technology and Management(IJITM)*. (In Press)
- Wenjuan Li, Jian Cao, Shiyu Qian, and Rajkumar Buyya. " TSLAM: A Trust-enabled Self-Learning Agent Model for Service Matching in the Cloud Market." *ACM Transactions on Autonomous and Adaptive Systems (TAAS)*, (Under the 2nd round review).
- Wenjuan Li, Jian Cao, Keyong Hu, IEEE, Jie Xu, and Rajkumar Buyya. " A Trust-based Agent Learning Model for Service Composition in Mobile Cloud Computing Environments.", *IEEE Access*. (Under review)

Visitor Self Profile: Vlado Stankovski

I am an associate professor of computer and information science at the University of Ljubljana, Slovenia. Areas of my interests include distributed, Grid and Cloud computing, and software engineering. I have worked on a variety of European Union funded research and innovation, technology integration projects, such as the DataMiningGrid (2004-2006), IntelliGrid (2004-2007), mOSAIC (2011-2013), ENTICE (2015-2018) and SWITCH (2015-2018) projects. I am currently engaged in the new Horizon 2020 European Union – Korea project called DECENTER (2018-2021), which covers areas, such as the Internet of Things, Cloud, Fog and Edge computing, and Blockchain.



I am very grateful to my host professor Rajkumar Buyya who gave me an opportunity to stay with the CLOUDS Lab – a World renown research group – in the period from 1 July – 30 September 2018. I follow the work of prof. Rajkumar Buyya since 2004, when we used GridBus in our DataMiningGrid project. On this occasion, during my stay, I shared my experience in various projects with the members of CLOUDS Lab, and at the same time, I closely followed their ongoing research activities. I also engaged in some lecturing and tutoring as part of the M.Sc. course COMP90015 Distributed Systems.

This was an inspiring experience, and above all, I made some excellent new friends. In the CLOUDS Lab I felt like being at home. Dear colleagues and friends, you are always welcome in Slovenia!

Our 2018 publications include:

1. Kochovski, P., Stankovski, V. Supporting smart construction with dependable edge computing infrastructure and applications. *Automation in Construction*, 2018, 85, pp. 182-192, doi: [10.1016/j.autocon.2017.10.008](https://doi.org/10.1016/j.autocon.2017.10.008).
2. Taherizadeh, S., Stankovski, V. Dynamic multi-level auto-scaling rules for containerized applications. *The Computer Journal*, 2018, pp. 1-24, doi: [10.1093/comjnl/bxy043/4993728](https://doi.org/10.1093/comjnl/bxy043/4993728).
3. Taherizadeh, S. Jones, A.C., Taylor, I., Zhao, Z., Stankovski, V. Monitoring self-adaptive applications within edge computing frameworks: A state-of-the-art review. *The Journal of Systems and Software*, 2018, 136, doi: [10.1016/j.jss.2017.10.033](https://doi.org/10.1016/j.jss.2017.10.033).
4. Štefanič, M., Stankovski, V., A review of technologies and applications for smart construction. *Proceedings of the Institution of Civil Engineers - Civil Engineering*, 2018, doi: [10.1680/jcien.17.00050](https://doi.org/10.1680/jcien.17.00050).
5. Taherizadeh, S., Stankovski, V., Grobelnik, M. A capillary computing architecture for dynamic Internet of Things - Orchestration of Microservices from Edge devices to Fog and Cloud providers: 2938. *Sensors*, 2018, 18, 9, doi: [10.3390/s18092938](https://doi.org/10.3390/s18092938).
6. Stankovski, V., Kochovski, P. Dependability of container-based data-centric systems. In: Ficco, M., Palmieri, F. (Eds). *Security and resilience in intelligent data-centric systems and communication networks*. London: Academic Press, an imprint of Elsevier, 2018, pp. 7-27, doi: [10.1016/B978-0-12-811373-8.00001-X](https://doi.org/10.1016/B978-0-12-811373-8.00001-X).
7. Stankovski, V., Prodan, R. Guest Editor's Introduction: Special Issue on Storage for the Big Data Era. *Journal of Grid Computing*, 2018, 16, doi: [10.1007/s10723-018-9427-5](https://doi.org/10.1007/s10723-018-9427-5).

Visitor Self Profile: Shreshth Tuli

I joined CLOUDS lab as a research intern for 10 weeks (15 May – 25 July) under the supervision of Prof. Rajkumar Buyya. I am an undergraduate student at Indian Institute of Technology, Delhi and currently in the 3rd year of my course. My current research interests lie primarily in System design, Edge computing and Blockchain and during my visit to University of Melbourne, I developed FogBus framework. FogBus is an end-to-end integration framework for edge and cloud computing paradigms that is lightweight and supports blockchain based data integrity.

We have submitted a paper regarding our work to the Journal of Systems and Software, which is currently under review.

My GitHub profile: <https://github.com/shreshthtuli>

FogBus GitHub repository: <https://github.com/Cloudslab/FogBus>

Preprint of the paper:

Shreshth Tuli, Redowan Mahmud, Shikhar Tuli, and Rajkumar Buyya. "FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing." *arXiv preprint arXiv:1811.11978*(2018).



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
- Open SensorWeb Architecture
- InterCloud – Peering and Federation of Clouds
- Content Delivery Networks
- Software Defined Networks
- Big Data
- Internet of Things (IoT)
- Fog and Edge Computing
- Application Targets include: ECG Monitoring and Analysis, Data Mining and Business Analytics, Brain Imaging (Dartmouth Medical School), and Geophysics (*Intrepid*).

Future Research is Driven By:

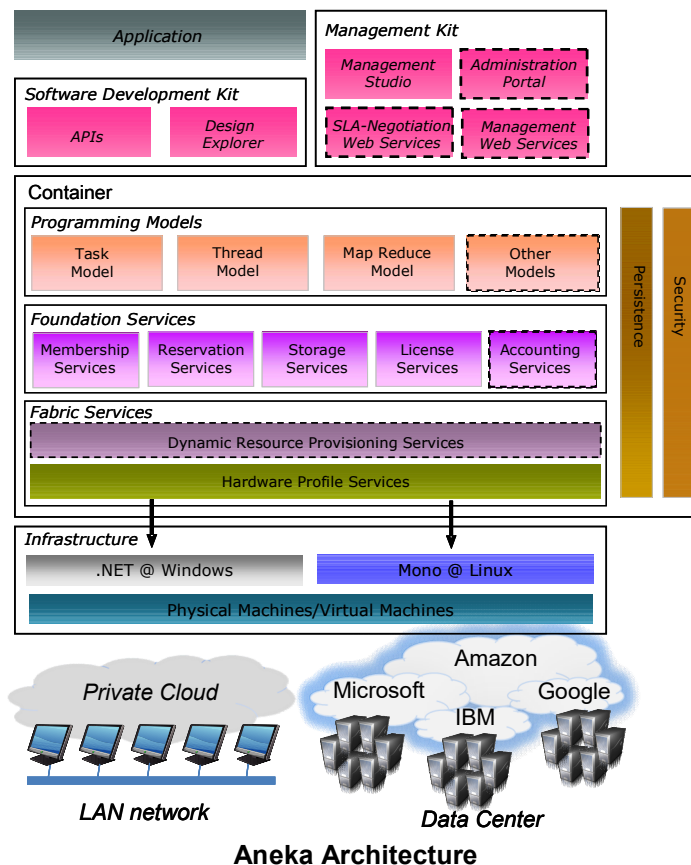
[A Manifesto for Future Generation Cloud Computing: Research Directions for the Next Decade,](#)

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 now 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)



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.

In this project 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.

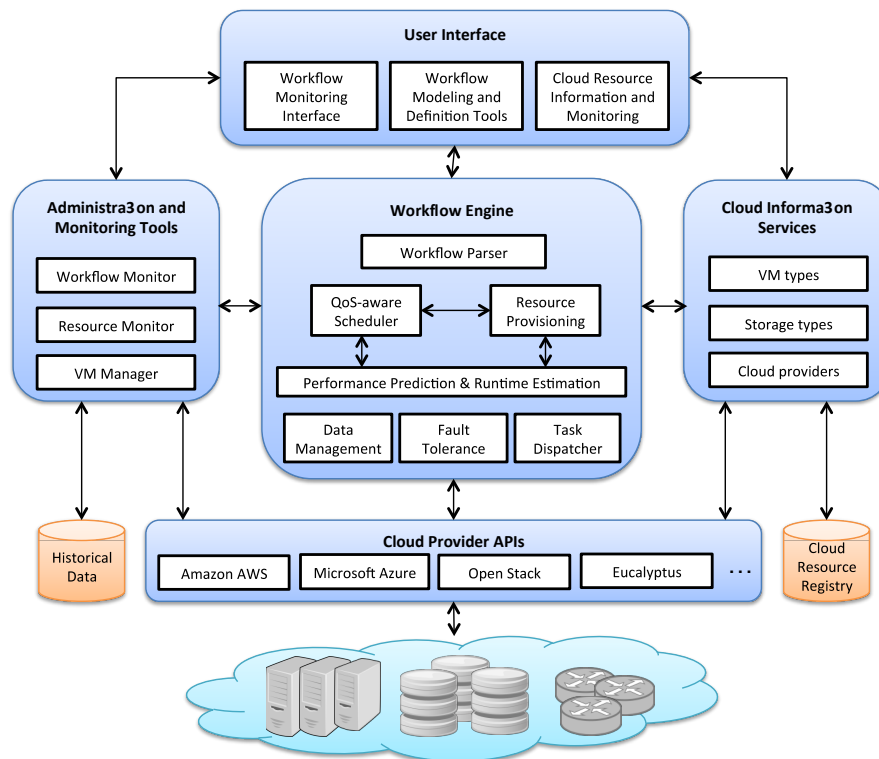


Fig. 1: Architecture of QoS-based workflow management and resource allocation system.

Some References:

- 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, Scientific Workflow Management System for Clouds, Software Architecture for Big Data and the Cloud, I. Mistrik, R. Bahsoon, N. Ali, M. Heisel, and B. Maxim (eds), 357-387pp, ISBN: 9780128054673, Morgan Kaufmann, Burlington, Massachusetts, USA, June 2017.
- 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.
- Maria A. Rodriguez and Rajkumar Buyya, Deadline based Resource Provisioning and Scheduling Algorithm for Scientific Workflows on Clouds, IEEE Transactions on Cloud Computing, Volume 2, Number 2, Pages: 222-235, ISSN: 2168-7161, IEEE Computer Society Press, USA, April-June 2014.
- 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.
- Atefeh Khosravi, Saurabh Kumar Garg, and Rajkumar Buyya, Energy and Carbon-Efficient Placement of Virtual Machines in Distributed Cloud Data Centers, Proceedings of the 19th International European Conference on Parallel and Distributed Computing (Euro-Par 2013, Springer, Berlin, Germany), Aachen, Germany, August 26-30, 2013.
- Anton Beloglazov and Rajkumar Buyya, OpenStack Neat: A Framework for Dynamic and Energy-Efficient Consolidation of Virtual Machines in OpenStack Clouds, Concurrency and Computation: Practice and Experience (CCPE), Volume 27, No. 5, Pages: 1310-1333, ISSN: 1532-0626, Wiley Press, New York, USA, April 2015.
- 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.
- Sukhpal Singh Gill and Rajkumar Buyya, [A Taxonomy and Future Directions for Sustainable Cloud Computing: 360 Degree View](#), ACM Computing Surveys, Volume 51, No. 5, Article No. 104, Pages: 1-33, ISSN 0360-0300, ACM Press, New York, USA, January 2019.

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.

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 and Rajkumar Buyya, CloudSimSDN-NFV: Modeling and Simulation of Network Function Virtualization and Service Function Chaining in Edge Computing Environments.

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.

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 (SPE)*, Volume 47, Issue 9, Pages: 1275-1296, ISSN: 0038-0644, 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, Kotagiri Ramamohanarao, and Rajkumar Buyya, Fog Computing: A Taxonomy, Survey and Future Directions, *Internet of Everything: Algorithms, Methodologies, Technologies and Perspectives*, B. DiMartino, K. Li, L. Yang, A. Esposito (eds), 103-130pp, ISBN 978-981-10-5860-8, Springer, Singapore, October 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.

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

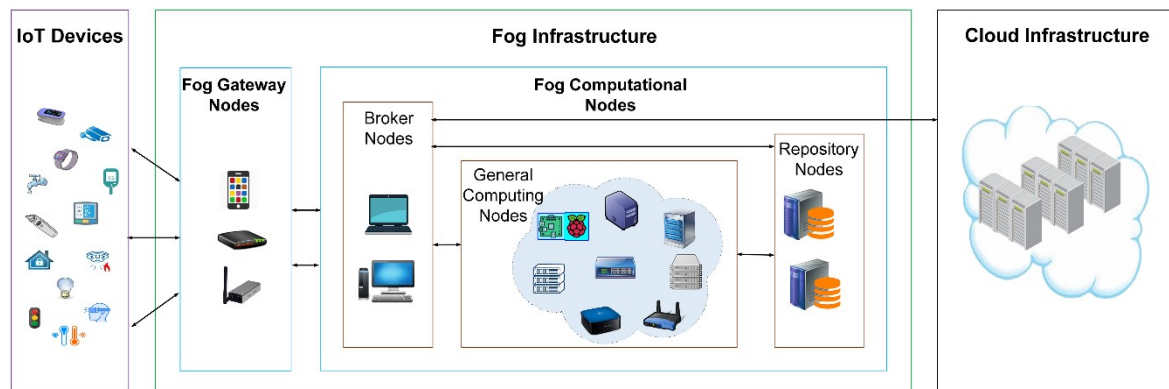
Web: <https://github.com/Cloudslab/FogBus>

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, users 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.

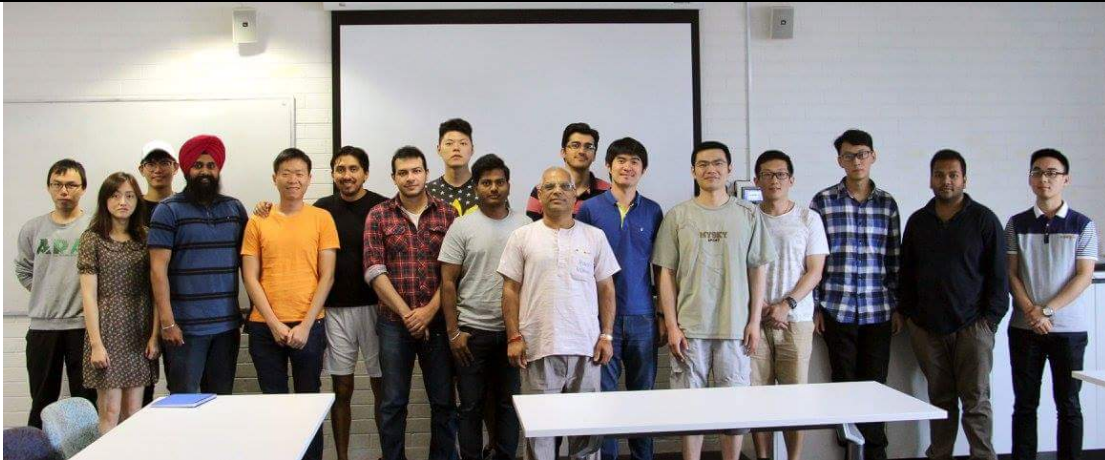


High-level view of FogBus-enabled integrated computing environments.

References:

- [1] Shreshth Tuli, Redowan Mahmud, Shikhar Tuli, and Rajkumar Buyya. FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing. arXiv preprint, <https://arxiv.org/abs/1811.11978> (Nov 29, 2018).

9. Moments with Visitors, Colleagues and International Hosts



A snap of CLOUDS lab members taken during Jay's PhD completion seminar (Jan 2018)



Lyon, France, February 27, 2018: With Laurent during visit to INRIA



Lyon, France, February 27, 2018: With Laurent and Marcos during visit to INRIA



With Prof Tian, UESTC, Chengdu, China, after my seminar on May 10, 2018.



During a Open Day 2018 demo with Dean of Engineering (Aug 2018)



During a Open Day 2018 demo with Harald (Aug 2018)

