

Cloud Computing and Distributed Systems (CLOUDS) Laboratory



www.cloudbus.org

Annual Report - 2019



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 2019, 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 2019 are:



- The Lab successfully hosted ARC research projects (Discovery and Linkage Projects) along with attracting two new research grants.
- Members of the CLOUDS Lab have authored 77 publications, which include 47 journal papers and 20 conference papers.
- The Lab's flagship Cloudbus Project has released various new modules for Aneka, CloudSim, iFogSim, and Fogbus. iFogSim, building on CloudSim, has emerged as a de-facto toolkit for modelling and simulation of Fog and Edge computing environments. It has been used by several researchers in academia and industries around the world.
- Excellence in Research for Australia (ERA) administered by the Australian Research Council (ARC), in its ERA 2018 evaluation report released in March 2019, offered Distributed Computing research at the University of Melbourne highest rating (5 - "well above" the world standard).
- Members have presented over 40 invited talks that include 12 keynotes delivered at international conferences/seminars held in Australia, India, Indonesia, Mauritius, Ireland, and UK.
- The Lab successfully hosted research activities of over 25 scholars, which include 16 PhD students and 3 Research Fellows.
- "2019 Web of Science Highly Cited Researcher" recognition from Thomson Reuters; and "**Best of the World**" in Computing Systems field (for quality, volume, and impact) recognition by the 2019 Australian Research Magazine.
- In 2019 alone, our papers have attracted over 11240 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, Iran, India, Italy, and Norway,
- Our Lab's spin-off company, Manjrasoft has been recognised as one of the Top 10 Most Scalable Cloud Solution Provider Companies by the "Mirror Review" Magazine.
- Members of the Lab have led community efforts such as (a) the organisation of conferences (e.g., IC FEC 2019 in Cyprus, CloudCom 2019 in Australia, HPCC 2019 in China) and (b) Editor-In-Chief of Journal of Software: Practice and Experience, which was established over 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

PhD Students

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

Collaborators

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

International Visitors

- Dr. Huaming Wu, Tianjin University, China, Jan-Feb 2019.
- Prof. Mohsen Kahani, Ferdowsi University of Mashhad, Iran, Jan-Aug 2019.
- Shreshth Tuli, Indian Institute of Technology Delhi, India, May-July 2019.
- Nipam Basumatary, Indian Institute of Technology Madras, India, May-July 2019.
- Riccardo Mancini, University of Pisa, Italy, July-Sept 2019.
- Dr. Sai Seshachalapati, Birla Institute of Technology and Science (BITS), Pilani, India, July-Dec. 2019.
- Dr. Zhicheng Cai, Nanjing University of Science and Technology, China, Aug 2019-Aug 2020.
- Amin Shahraki, University of Oslo, Norway, Aug. 2019-Feb. 2020.

- Dr. Xiaogang Wang, Shanghai Dianji University, China, September 2019-September 2020.
- Linna Ruan, Beijing University of Posts and Telecommunications (BUPT), China. Sept. 2019-Sept. 2020.
- Dongcheng Zhao, University of Electronic Science and Technology of China, China, Oct. 2019-Oct.2020.

3. Competitive Grants Funded Projects and Programs - Active

Australian Research Council (ARC)

- R. Buyya, Algorithms and Software Systems for Management of Software-Defined Clouds, Discovery Project, Australian Research Council (ARC), 2016-2020. Amount: \$410,000.

Other National Grants

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

Industry and Melbourne University Grants

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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 |
|--------------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Books/Proceedings | 1 | 1 | 1 | 1 | 5 | 4 | 3 | 5 | 2 | 3 | 2 | 2 | 1 | 2 | 3 | 1 | 2 | 2 |
| Journal Papers | 6 | 1 | 4 | 5 | 6 | 4 | 10 | 13 | 8 | 9 | 15 | 17 | 17 | 17 | 24 | 31 | 43 | 47 |
| Book Chapters | 1 | 0 | 0 | 4 | 4 | 2 | 4 | 11 | 3 | 13 | 3 | 1 | 2 | 3 | 6 | 10 | 1 | 8 |
| Conference Papers | 4 | 7 | 9 | 16 | 15 | 24 | 22 | 27 | 15 | 14 | 12 | 6 | 14 | 21 | 9 | 11 | 15 | 20 |
| Magazine Articles | 0 | 0 | 1 | 2 | 4 | 2 | 0 | 1 | 2 | 1 | 0 | 5 | 2 | 3 | 1 | 1 | 1 | 0 |
| <i>Total</i> | 12 | 9 | 15 | 28 | 34 | 36 | 39 | 57 | 30 | 40 | 32 | 31 | 36 | 46 | 43 | 54 | 62 | 77 |

Books/Proceedings Edited

- Rajkumar Buyya and Satish N. Srirama (eds.), [Fog and Edge Computing: Principles and Paradigms](#), 480 pages, ISBN: 978-111-95-2498-4, Wiley Press, New York, USA, January 2019.
- H. S. Saini, Rishi Sayal, A. Govardhan, and Rajkumar Buyya (editors), [Innovations in Computer Science and Engineering](#): Proceedings of the Sixth International Conference, ISBN: 978-981-13-7082-3, Springer, Singapore, May 2019.

Book Chapters

- Chii Chang, Satish Narayana Srirama, and Rajkumar Buyya, [Internet of Things \(IoT\) and New Computing Paradigms](#), Fog and Edge Computing: Principles and Paradigms, R. Buyya and S. Srirama (eds), 3-24pp, ISBN: 978-111-95-2498-4, Wiley Press, New York, USA, January 2019.
- Adel Nadjaran Toosi, Redowan Mahmud, Qinghua Chi, and Rajkumar Buyya, [Management and Orchestration of Network Slices in 5G, Fog, Edge and Clouds](#), Fog and Edge Computing: Principles and Paradigms, R. Buyya and S. Srirama (eds), 79-102pp, ISBN: 978-111-95-2498-4, Wiley Press, New York, USA, January 2019.
- 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), 433-466pp, ISBN: 978-111-95-2498-4, Wiley Press, New York, USA, January 2019.
- Muhammed Tawfiqul Islam and Rajkumar Buyya, [Resource Management and Scheduling for Big Data Applications in Cloud Computing Environments](#), Handbook of Research on Cloud Computing and Big Data Applications in IoT, B. Gupta and D. Agrawal (eds), 1-23pp, ISBN-13: 978-1522584070, IGI Global, USA, 2019.
- Rajinder Sandhu, Adel Nadjaran Toosi, and Rajkumar Buyya, [An API for Development of User-Defined Scheduling Algorithms in Aneka PaaS Cloud Software: User Defined Schedulers in Aneka PaaS Cloud Software](#), Handbook of Research on Cloud Computing and Big Data Applications in IoT, B. Gupta and D. Agrawal (eds), 170-187pp, ISBN-13: 978-1522584070, IGI Global, USA, 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.
- Sukhpal Singh Gill and Rajkumar Buyya, [Bio-inspired Algorithms for Big Data Analytics: A Survey, Taxonomy and Open Challenges](#), Big Data Analytics for Intelligent Healthcare

- Management, H. Das, N. Dey, B. Naik, and H S Behera (eds), 1-17pp, ISBN: 978-0128181461, Elsevier, San Diego, USA, April 2019.
10. Arash Shaghaghi, Mohamed Ali Kaafar, Rajkumar Buyya, and Sanjay Jha, [Software-Defined Network \(SDN\) Data Plane Security: Issues, Solutions and Future Directions](#), Handbook of Computer Networks and Cyber Security: Principles and Paradigms, B. Gupta, G. Perez, D. Agrawal, and D. Gupta (eds), 341-387pp, ISBN: 978-3-030-22276-5, Springer, Switzerland, October 2019.

Journal Editorials

11. Gaurav Somani, Xinghui Zhao, Satish Narayana Srirama, and Rajkumar Buyya, [Integration of Cloud, Internet of Things, and Big Data Analytics](#), Software: Practice and Experience, Volume 49, Number 4, Pages: 561-564, ISSN: 0038-0644, Wiley Press, New York, USA, April 2019.
12. Mohammad Shojafar, Zahra Pooranian, Mehdi Sookhak, and Rajkumar Buyya, [Recent Advances in Cloud Data Centers toward Fog Data Centers](#), Concurrency and Computation: Practice and Experience, Volume 31, No. 8, Pages: 1-3, Wiley Press, New York, USA, April 2019.

Journal Papers

13. Jungmin Son and Rajkumar Buyya, [SDCon: Integrated Control Platform for Software-Defined Clouds](#), IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 30, No. 1, Pages: 230-244, ISSN: 1045-9219, IEEE CS Press, USA, January 2019.
14. 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.
15. 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 Milojevic, 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.
16. Tingming Wu, Junlong Zhou, Mingsong Chen, Tongquan Wei, Shiyan Hu, and Rajkumar Buyya, [Energy-Aware Virtual Machine Allocation for Cloud with Resource Reservation](#), Journal of Systems and Software (JSS), Volume 147, Pages: 147-161, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, January 2019.
17. Siva Kumar Gavvala, G R Gangadharan, Chandrashekar Jatoth, and Rajkumar Buyya, [QoS-aware Cloud Service Composition using Eagle Strategy](#), Future Generation Computer Systems, Volume 90, Pages: 273-290, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, January 2019.
18. 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 (CCPE), Volume 31, No. 1, Pages: 1-29, ISSN: 1532-0626, Wiley Press, New York, USA, January 10, 2019.
19. 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, Volume 52, No. 1, Article No. 8, Pages: 1-27, ISSN 0360-0300, ACM Press, New York, USA, February 2019.

20. Rustem Dautov, Salvatore Distefano, and Rajkumar Buyya, [Hierarchical Data Fusion for Smart Healthcare](#), Journal of Big Data, Volume 6, Article No: 19, Pages: 1-23, ISSN: 2196-1115, Springer Nature, Switzerland, February 2019.
21. Xunyun Liu and Rajkumar Buyya, [Performance-Oriented Deployment of Streaming Applications on Cloud](#), IEEE Transactions on Big Data, Volume 5, Number 1, Pages: 46-59, ISSN: 2332-7790, IEEE Computer Society Press, USA, March 2019.
22. Redowan Mahmud, Kotagiri Ramamohanarao, and Rajkumar Buyya, [Latency-aware Application Module Management for Fog Computing Environments](#), ACM Transactions on Internet Technology (TOIT), Volume 19, No. 1, Article 9, Pages: 1-21, ISSN:1533-5399, ACM Press, New York, USA, March 2019.
23. Anwesha Mukherjee, Debashis De, and Rajkumar Buyya, [E2R-F2N: Energy-Efficient Retailing using a Femtolet-based Fog Network](#), Software: Practice and Experience (SPE), Volume 49, Issue 3, Pages: 498-523, ISSN: 0038-0644, Wiley Press, New York, USA, March 2019.
24. Jungmin Son and Rajkumar Buyya, [Priority-aware VM Allocation and Network Bandwidth Provisioning in Software-Defined Networking \(SDN\)-enabled Clouds](#), IEEE Transactions on Sustainable Computing (T-SUSC), Volume 4, Number 1, Pages: 17-28, ISSN: 2377-3782, IEEE Computer Society Press, USA, January-March 2019.
25. 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.
26. Wenjuan Li, Jian Cao, Keyong Hu, Jie Xu, and Rajkumar Buyya, [A Trust-based Agent Learning Model for Service Composition in Mobile Cloud Computing Environments](#), IEEE Access, Volume 7, Pages: 34207-34226, ISSN: 2169-3536, IEEE Press, New Jersey, USA, March 2019.
27. Stelios Sotiriadis, Nik Bessis, Cristiana Amza, Rajkumar Buyya, [Elastic Load Balancing for Dynamic Virtual Machine Reconfiguration Based on Vertical and Horizontal Scaling](#), IEEE Transactions on Services Computing (TSC), Volume 12, Number 2, Pages: 319-334, ISSN: 1939-1374, IEEE Computer Society Press, USA, March-April 2019.
28. Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, [ACAS: An Anomaly-based Cause Aware Auto-Scaling Framework for Clouds](#), Journal of Parallel and Distributed Computing (JPDC), Volume 126, Pages: 107-120, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, April 2019.
29. Yaser Mansouri and Rajkumar Buyya, [Dynamic Replication and Migration of Data Objects with Hot-spot and Cold-spot Statuses Across Storage Data Centers](#), Journal of Parallel and Distributed Computing (JPDC), Volume 126, Pages: 121-133, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, April 2019.
30. Diptendu Sinha Roy, Ranjit K. Behera, K. Hemant Kumar Reddy, and Rajkumar Buyya, [A Context-Aware Fog Enabled Scheme for Real-Time Cross-Vertical IoT Applications](#), IEEE Internet of Things Journal, Volume 6, Number 2, Pages: 2400-2412, ISSN: 2168-7161, IEEE Computer Society Press, USA, April 2019.
31. Maria Rodriguez Sossa and Rajkumar Buyya, [Container-based Cluster Orchestration Systems: A Taxonomy and Future Directions](#), Software: Practice and Experience (SPE), Volume 49, Issue 5, Pages: 698-719, ISSN: 0038-0644, Wiley Press, New York, USA, May 2019.
32. Chandrashekar Jatoth, G.R. Gangadharan, Rajkumar Buyya, [Optimal Fitness Aware Cloud Service Composition using an Adaptive Genotypes Evolution based Genetic Algorithm](#), Future Generation Computer Systems, Volume 94, Pages: 185-198, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, May 2019.
33. Roopa M.S., Santosh Pattar, Rajkumar Buyya, Venugopal K.R., S.S. Iyengar, and L.M. Patnaik, [Social Internet of Things \(SIoT\): Foundations, Thrust Areas, Systematic Review and Future Directions](#), Computer Communications, Volume 139, Pages: 32-57, ISSN: 0140-3664, Elsevier Science, Amsterdam, The Netherlands, May 2019.
34. Jungmin Son and Rajkumar Buyya, [Latency-aware Virtualized Network Function Provisioning for Distributed Edge Clouds](#), Journal of Systems and Software (JSS),

- Volume 152, Pages: 24-31, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, June 2019.
35. Adel Nadjaran Toosi, Jungmin Son, Qinghua Chi, and Rajkumar Buyya, [ElasticSFC: Auto-Scaling Techniques for Elastic Service Function Chaining in Network Functions Virtualization-based Clouds](#), Journal of Systems and Software (JSS), Volume 152, Pages: 108-119, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, June 2019.
 36. Bowen Zhou, Satish Srirama, and Rajkumar Buyya, [An Auction-based Incentive Mechanism for Heterogeneous Mobile Clouds](#), Journal of Systems and Software (JSS), Volume 152, Pages: 151-164, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, June 2019.
 37. 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), Volume 13, Number 4, Article No.: 16, Pages: 1-41, ISSN: 1556-4665, ACM Press, New York, USA, July 2019.
 38. Safiollah Heidari and Rajkumar Buyya, [Quality of Service \(QoS\)-driven Resource Provisioning for Large-scale Graph Processing in Cloud Computing Environments: Graph Processing-as-a-Service \(GPaaS\)](#), Future Generation Computer Systems (FGCS), Volume 96, Pages: 490-501, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, July 2019.
 39. Chandrashekar Jatoth, G. R. Gangadharan, Ugo Fiore, and Rajkumar Buyya, [SELCLLOUD: A Hybrid Multi-Criteria Decision Making Model for Selection of Cloud Services](#), Soft Computing Journal, Volume 23, No. 13, Pages: 4701-4715, ISSN: 1432-7643, Springer Nature, Berlin, Germany, July 2019.
 40. Dawei Sun, Shang Gao, Xunyun Liu, Fengyun Li, Xinqi Zheng, and Rajkumar Buyya, [State and Runtime-Aware Scheduling in Elastic Stream Computing Systems](#), Future Generation Computer Systems (FGCS), Volume 97, Pages: 194-209, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, August 2019.
 41. Shreshth Tuli, Redowan Mahmud, Shikhar Tuli, and Rajkumar Buyya, [FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing](#), Journal of Systems and Software (JSS), Volume 154, Pages: 22-36, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, August 2019.
 42. Sukhpal Singh Gill, Peter Garraghan, and Rajkumar Buyya, [ROUTER: Fog Enabled Cloud based Intelligent Resource Management Approach for Smart Home IoT Devices](#), Journal of Systems and Software (JSS), Volume 154, Pages: 125-138, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, August 2019.
 43. Yaser Mansouri, Adel Nadjaran Toosi, and Rajkumar Buyya, [Cost Optimization for Dynamic Replication and Migration of Data in Cloud Data Centers](#), IEEE Transactions on Cloud Computing (TCC), Volume 7, Number 3, Pages: 705-718, ISSN: 2168-7161, IEEE Computer Society Press, USA, July-September 2019.
 44. Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, [Performance-Aware Management of Cloud Resources: A Taxonomy and Future Directions](#), ACM Computing Surveys, Volume 52, No. 4, Article No. 84, Pages: 1-37, ISSN 0360-0300, ACM Press, New York, USA, September 2019.
 45. TianZhang He, Adel Nadjaran Toosi, Rajkumar Buyya, [Performance Evaluation of Live Virtual Machine Migration in SDN-enabled Cloud Data Centers](#), Journal of Parallel and Distributed Computing (JPDC), Volume 131, Pages: 55-68, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, September 2019.
 46. Yinhao Li, Awa Alqahtani, Ellis Solaiman, Charith Perera, Prem Prakash Jayaraman, Rajkumar Buyya, Graham Morgan, and Rajiv Ranjan, [IoT-CANE: A Unified Knowledge Management System for Data-Centric Internet of Things Application Systems](#), Journal of Parallel and Distributed Computing (JPDC), Volume 131, Pages: 161-172, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, September 2019.
 47. 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, Volume 17, Number 3,

- Pages: 385-417, ISSN: 1570-7873, Springer Science+Business Media B.V., New York, USA, September 2019.
48. Minxian Xu and Rajkumar Buyya, [BrownoutCon: A Software System based on Brownoutand Containers for Energy-Efficient Cloud Computing](#), Journal of Systems and Software (JSS), Volume 155, Pages: 91-103, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, September 2019.
 49. Sukhpal Singh Gill, Peter Garraghan, Vlado Stankovski, Giuliano Casale, Ruppia K. Thulasiram, Soumya K. Ghosh, Kotagiri Ramamohanarao, and Rajkumar Buyya, [Holistic Resource Management for Sustainable and Reliable Cloud Computing: An Innovative Solution to Global Challenge](#), Journal of Systems and Software (JSS), Volume 155, Pages: 104-129, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, September 2019.
 50. 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 31, No. 17, Pages: 1-15, ISSN: 1532-0626, Wiley Press, New York, USA, September 2019.
 51. Deepsubhra Guha Roy, Puja Das, Debashis De, and Rajkumar Buyya, [QoS-aware Secure Transaction Framework for Internet of Things using Blockchain Mechanism](#), Journal of Network and Computer Applications (JNCA), Volume 144, Pages: 59-78, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, October 2019.
 52. Redowan Mahmud, Satish Narayana Srirama, Ramamohanarao Kotagiri, and Rajkumar Buyya, [Quality of Experience \(QoE\)-aware Placement of Applications in Fog Computing Environments](#), Journal of Parallel and Distributed Computing (JPDC), Volume 132, Pages: 190-203, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, October 2019.
 53. Paola G. Vinueza Naranjo, Zahra Pooranian, Mohammad Shojafar, Mauro Conti, and Rajkumar Buyya, [FOCAN: A Fog-supported Smart City Network Architecture for Management of Applications in the Internet of Everything Environments](#), Journal of Parallel and Distributed Computing (JPDC), Volume 132, Pages: 274-283, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, October 2019.
 54. Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, [Performance Anomaly Detection Using Isolation-Trees in Heterogeneous Workloads of Web Applications in Computing Clouds](#), Concurrency and Computation: Practice and Experience (CCPE), Volume 31, No. 20, Pages: 1-17, ISSN: 1532-0626, Wiley Press, New York, USA, October 2019.
 55. Caesar Wu, Rajkumar Buyya, and Kotagiri Ramamohanarao, [Cloud Pricing Models: Taxonomy, Survey and Interdisciplinary Challenges](#), ACM Computing Survey, Volume 52, No. 6, Article No. 108, Pages: 1-36, ISSN 0360-0300, ACM Press, New York, USA, October 2019.
 56. Mohammad Goudarzi, Marimuthu Palaniswami, and Rajkumar Buyya, [A Fog-driven Dynamic Resource Allocation Technique in Ultra Dense Femtocell Networks](#), Journal of Network and Computer Applications (JNCA), Volume 145, Pages: ??, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, November 2019.
 57. Anwesha Mukherjee, Priti Deb, Debashis De, and Rajkumar Buyya, [IoT-F2N: An Energy-Efficient Architectural Model for IoT using Femtolet-based Fog Network](#), The Journal of Supercomputing, Volume 75, Number 1, Pages: 7125-7146, ISSN: 0920-8542, Springer Science+Business Media, Berlin, Germany, November 2019.
 58. Caesar Wu, Rajkumar Buyya, and Kotagiri Ramamohanarao, [Value-based Cloud Price Modeling for Segmented Business to Business Market](#), Future Generation Computer Systems (FGCS), Volume 101, Pages: 502-523, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, December 2019.
 59. Jungmin Son, TianZhang He and Rajkumar Buyya, [CloudSimSDN-NFV: Modeling and Simulation of Network Function Virtualization and Service Function Chaining in Edge Computing Environments](#), Software: Practice and Experience (SPE), Volume 49, No. 12, Pages: 1748-1764, ISSN: 0038-0644, Wiley Press, New York, USA, December 2019.

Magazine Papers

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Conference Papers

60. H M Dipu Kabir, Abadhan S. Sabyasachi, Abbas Khosravi, M Anwar Hosen, Saeid Nahavandi, and Rajkumar Buyya, [A Cloud Bidding Framework for Deadline Constrained Jobs](#), Proceedings of 2019 IEEE International Conference on Industrial Technology (ICIT 2019, IEEE Press, USA), Melbourne, Australia, February 13-15, 2019.
61. H M Dipu Kabir, Abbas Khosravi, M Anwar Hosen, Saeid Nahavandi, and Rajkumar Buyya, [Probability Density for Amazon Spot Instance Price](#), Proceedings of 2019 IEEE International Conference on Industrial Technology (ICIT 2019, IEEE Press, USA), Melbourne, Australia, February 13-15, 2019.
62. Geeta C M, Mithila Lakshmi G, Shreyas Raju R G, Raghavendra S, Rajkumar Buyya, Venugopal K R, S S Iyengar, and L M Patnaik, [STLDAS: Secure Two Level Deduplication and Auditing of Shared Data in Cloud](#), Proceedings of the 2019 IEEE Region 10 Symposium (TENSYP, IEEE Press, New York, USA), Kolkata, India, June 7-9, 2019.
63. Imairi Eitiveni, Sherah Kurnia, and Rajkumar Buyya, [A Traceability System for Sustainability Transformation in the Food Supply Chain: An Affordance Theory Perspective](#), Proceedings of the 27th European Conference on Information Systems (ECIS 2019), Stockholm, Sweden, June 8-14, 2019.
64. Satish Kumar, Rami Bahsoon, Tao Chen, and Rajkumar Buyya, [Identifying and Estimating Technical Debt for Service Composition in SaaS Cloud](#), Proceedings of the 16th IEEE International Conference on Web Services (ICWS 2019, IEEE CS Press, USA), Milan, Italy, July 8-13, 2019.
65. Santosh Pattar, Dwaraka S Kulkarni, Darshil Vala, Rajkumar Buyya, Venugopal K R, S.S. Iyengar, and L.M. Patnaik, [Progressive Search Algorithm for Service Discovery in an IoT Ecosystem](#), Proceedings of the 12th IEEE International Conference on Internet of Things (iThings 2019, IEEE CS Press, USA), Atlanta, Georgia, USA, July 14-17, 2019.
66. Shreshth Tuli, Nipam Basumatary, and Rajkumar Buyya, [EdgeLens: Deep Learning based Object Detection in Integrated IoT, Fog and Cloud Computing Environments](#), Proceedings of the 4th IEEE International Conference on Information Systems and Computer Networks (ISCON 2019, IEEE Press, USA), Mathura, India, November 21-22, 2019.
67. Santosh Pattar, Lakshmi K. N., Darshil Vala, Venkatesh, Rajkumar Buyya, Venugopal K. R., S. S. Iyengar, and L. M. Patnaik, [Location-aware IoT Search Framework based on Data Messaging and Aggregation Techniques](#), in Proceedings of the 2019-IEEE Women Institute of Technology Conference on Electrical and Computer Engineering (WITCON ECE, IEEE Press, USA), Dehradun, India, November 22-23, 2019.
68. Redowan Mahmud, Kotagiri Ramamohanarao, and Rajkumar Buyya, [Edge Affinity-based Management of Applications in Fog Computing Environments](#), 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.
69. Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya, [Microservices-based IoT Application Placement within Heterogeneous and Resource Constrained Fog Computing Environments](#), Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2019, IEEE CS Press, USA), Auckland, New Zealand, Dec. 2-5, 2019.
70. 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.

71. Santosh Pattar, Ritika, Darshil Vala, Rajkumar Buyya, Venugopal K. R., S. S. Iyengar, and L. M. Patnaik, [Device Discovery Techniques for Industrial Internet of Things through Predictive Analytic Mechanism](#), Proceedings of the 2019 3rd International Conference on Security with Intelligent Computing and Big-data Services (SICBS 2019, Springer Press), Taipei, Taiwan, December 4-6, 2019.
 72. Shreshth Tuli, Shikhar Tuli, Udit Jain, Rajkumar Buyya, [APEX: Adaptive Ext4 File System for Enhanced Data Recoverability in Edge Devices](#), Proceedings of the 11th IEEE International Conference on Cloud Computing Technology and Science (CloudCom 2019, IEEE CS Press, USA), Sydney, Australia, December 11-13, 2019.
 73. Shreya Ghosh, Soumya Ghosh and Rajkumar Buyya, [MovCloud: A Cloud-enabled Framework to Analyse Movement Behaviors](#), Proceedings of the 11th IEEE International Conference on Cloud Computing Technology and Science (CloudCom 2019, IEEE CS Press, USA), Sydney, Australia, December 11-13, 2019.
 74. Santosh Pattar, Sandhya CR, Darshil Vala, Dharamendra Chouhan, Rajkumar Buyya, Venugopal KR, S. S. Iyengar, and L. M. Patnaik, [Context-Oriented User-Centric Search System for the IoT Based on Fuzzy Clustering](#), Proceedings of the 2nd International Conference on Computational Intelligence, Security and Internet of Things (ICCISIoT 2019, Springer Nature Singapore), Agartala, India, December 13-14, 2019.
 75. Jaydeep Das, Sourav K. Addya, Soumya K. Ghosh, and Rajkumar Buyya, [Optimal Geospatial Query Placement in Cloud](#), Proceedings of the International Conference on Intelligent and Cloud Computing (ICICC-2019, Springer, Germany), Bhubaneswar, India, December 16-17, 2019.
 76. Riccardo Mancini, Shreshth Tuli, Tommaso Cucinotta, and Rajkumar Buyya, [iGateLink: A Gateway Library for Linking IoT, Edge, Fog and Cloud Computing Environments](#), Proceedings of the International Conference on Intelligent and Cloud Computing (ICICC-2019, Springer, Germany), Bhubaneswar, India, December 16-17, 2019.
 77. Jaydeep Das, Anwesha Mukherjee, Soumya K. Ghosh, and Rajkumar Buyya, [Geo-Cloudlet: Time and Power Efficient Geospatial Query Resolution using Cloudlet](#), Proceedings of the 11th International Conference on Advanced Computing (ICoAC 2019, IEEE Press, New York, USA), Chennai, India, December 18-20, 2019.
 78. Geeta C Mara, Shreyas R G, Raghavendra S, Rajkumar Buyya, Venugopal Kuppanna Rajuk, Sitharama Iyengar, LM Patnaik, [SDVADC: Secure Deduplication and Virtual Auditing of Data in Cloud](#), Proceedings of the Third International Conference on Computing and Network Communications (CoCoNet 2019, Elsevier - Procedia Computer Science), Trivandrum, Kerala, India, December 18-21, 2019.
 79. Santosh Pattar, Sandhya C R, Darshil Vala, Rajkumar Buyya, Venugopal K R, S S Iyengar, and L M Patnaik, [SoCo-ITS: Service Oriented Context Ontology for Intelligent Transport System](#), Proceedings of the 7th International Conference on Information Technology (ICIT 2019, ACM Press, New York, USA), Shanghai, China, December 20-23, 2019.
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5. Invited Presentations and Outreach

By the Lab Director:

Keynote Talks at International Conferences

1. New Frontiers in Cloud and Fog Computing for Big Data and Internet-of-Things (IoT) Applications, 2nd International Conference on Software Engineering and Information Management (ICSIM 2019) and 2nd International Conference on Big Data and Smart Computing, Singaraja, Bali, Indonesia, January 10-13, 2019.
2. New Frontiers in Cloud and Edge Computing, International Conference on Advances in Computing and Data Sciences (ICACDS 2019), Inderprastha Engineering College, Gaziabad, UP, India, April 12-13, 2019.
3. New Frontiers in Cloud and Edge Computing, 4th IEEE International Conference on Internet of Things: Smart Innovation & Usage (IOT-SIU2019), Krishna Engineering College, Ghaziabad, UP, India, April 18-19, 2019.
4. New Frontiers in Cloud and Edge Computing, International Conference on Recent Trends in Computer Applications & Information Technology (RTCAIT). Maharishi Markandeshwar University, Mullana, Haryana, India, April 19-20, 2019.
5. New Frontiers in Cloud and Edge Computing, 4th International Conference on Advances in Computing and Information Technology (IACIT- 2019), REVA University, Bangalore, India, May 10-11, 2019.
6. New Frontiers in Cloud and Edge Computing for Big Data and Internet-of-Things (IoT) Applications, Data Science for the Natural Environment (DSNE 2019) Conference, Lancaster, UK, July 8-9, 2019.
7. New Frontiers in Cloud and Edge Computing for Big Data and Internet-of-Things (IoT) Applications, 17th International Conference on High Performance Computing and Simulation (HPCS 2019), Dublin, Ireland, July 15-19, 2019.
8. [New Frontiers in Cloud and Edge Computing](#), International Conference on Recent Trends in IoT and Blockchain (ICRTIB-2019), GIET University, Gunupur, India, October 19-20, 2019.
9. New Frontiers in Cloud and Edge Computing, 9th International Conference on Computer and Knowledge Engineering (ICCKE 2019), Ferdowsi University of Mashhad, Iran, October 24-25, 2019.
10. New Frontiers in Cloud and Edge Computing, 12th IEEE/ACM International Conference on Utility and Cloud Computing (UCC2019), Auckland, New Zealand, December 2-5, 2019.
11. New Frontiers in Cloud and Edge Computing, International Conference on Computing Analytics and Networking (ICCAN-2019), Bhubaneswar, India, Dec. 14-15, 2019.
12. New Frontiers in Cloud and Edge Computing, International Conference on Intelligent and Cloud Computing (ICICC-2019), Bhubaneswar, India, Dec. 16-17, 2019.

National Conferences

1. National Seminar on New Frontiers in Cloud and Edge Computing, National Institute of Technical Teachers Training and Research (NITTTR), Chandigarh, India, April 23, 2019.

Seminars - in Cloud Computing area:

1. New Frontiers in Fog and Edge Computing for Internet-of-Things (IoT) Applications, National Institute of Technology Karnataka, Surathkal, India, Jan. 1, 2019.
2. New Frontiers in Fog and Edge Computing for Internet-of-Things (IoT) Applications, Institute for Development and Research in Banking Technology (IDRBT), Hyderabad, India, Jan. 2, 2019.
3. New Frontiers in Fog and Edge Computing for Internet-of-Things (IoT) Applications, Vasavi College of Engineering, Hyderabad, India, Jan. 4, 2019.

4. New Frontiers in Fog and Edge Computing for Internet-of-Things (IoT) Applications, Karnatak Arts Science and Commerce College, Bidar, India, Jan. 5, 2019.
5. New Frontiers in Fog and Edge Computing for Internet-of-Things (IoT) Applications, University of Hyderabad, Hyderabad, India, Jan. 7, 2019.
6. New Frontiers in Cloud and Edge Computing, G B Pant Government Engineering College, New Delhi, India, April 11, 2019.
7. New Frontiers in Cloud and Edge Computing, GLA University, Mathura, India, April 14, 2019.
8. New Frontiers in Cloud and Edge Computing, Jaypee Institute of Information Technology (JIIT), Noida, India, April 17, 2019.
9. New Frontiers in Cloud and Edge Computing, National Institute Of Technology, Kurukshetra, India, April 20, 2019.
10. New Frontiers in Cloud and Edge Computing, University Institute of Engineering and Technology (UIET), Kurukshetra University, Haryana, India, April 22, 2019.
11. New Frontiers in Cloud and Edge Computing, Chandigarh University, Punjab, India, April 24, 2019.
12. New Frontiers in Cloud and Edge Computing, Indian Institute of Technology Ropar (IIT Ropar), Punjab, India, April 24, 2019.
13. New Frontiers in Cloud and Edge Computing, Thapar University, Patiala, Punjab, India, April 25, 2019.
14. New Frontiers in Cloud and Edge Computing, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India, April 26, 2019.
15. New Frontiers in Cloud and Edge Computing, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India, April 27, 2019.
16. New Frontiers in Cloud and Edge Computing, Dr. BR Ambedkar National Institute of Technology (NIT), Jalandhar, Punjab, India, April 29, 2019.
17. New Frontiers in Cloud and Edge Computing, Lovely Professional University (LPU), Phagwara, Punjab, India, April 30, 2019.
18. New Frontiers in Cloud and Edge Computing, I.K. Gujral Punjab Technical University Jalandhar (IKGPTU), Kapurthala, Punjab, India, April 30, 2019.
19. New Frontiers in Cloud and Edge Computing, Madan Mohan Malaviya University of Technology, Gorakhpur, UP, India, May 4, 2019.
20. New Frontiers in Cloud and Edge Computing, The University of Mauritius, Reduit, Mauritius, June 21, 2019.
21. New Frontiers in Cloud and Edge Computing, The University of Derby, UK, July 1, 2019.
22. New Frontiers in Cloud and Edge Computing, Newcastle University, UK, July 4, 2019.
23. New Frontiers in Cloud and Edge Computing, The University of Manchester, UK, July 5, 2019.
24. New Frontiers in Cloud and Edge Computing, Lancaster University, UK, July 9, 2019.
25. New Frontiers in Cloud and Edge Computing, Liverpool John Moores University, Liverpool, UK, July 10, 2019.
26. New Frontiers in Cloud and Edge Computing, Indian Institute of Technology, Kharagpur, West Bengal, India, Dec. 18, 2019.
27. New Frontiers in Cloud and Edge Computing, Nirma University, Ahmedabad, Gujarat, India, Dec. 20, 2019.
28. New Frontiers in Cloud and Edge Computing, Jadavpur University, Kolkata, West Bengal, India, Dec. 30, 2019.

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.

Conference Organisation/ Program Committee Memberships

1. General Co-Chair, 3rd IEEE International Conference on Fog and Edge Computing (ICFEC 2019) (in conjunction with IEEE/ACM CCGrid 2019), May 16, 2019, Larnaca, Cyprus.
2. General Co-Chair, 11th IEEE International Conference on Cloud Computing Technology and Science (CloudCom 2019), December 11-13, 2019, Sydney, Australia.
3. PC Co-Chair, 21st IEEE International Conference on High Performance Computing and Communications (HPCC-2019), August 10-12, 2019, Zhangjiajie, Hunan, China.
4. 20th International Conference on Parallel and Distributed Computing, Applications and Technologies (PDCAT 2019), December 5-7, 2019, Gold Coast, Australia.
5. 19th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid 2019), May 14-17, 2019, Larnaca, Cyprus.
6. 39th IEEE International Conference on Distributed Computing Systems (ICDCS 2019), July 7-10, 2019, Dallas, Texas, USA.
7. The 28th International Conference on Computer Communications and Networks (ICCCN 2019), July 29 - August 1, 2019, Valencia, Spain.
8. 17th International Conference on Service Oriented Computing (ICSOC 2019), October 28-31, 2019, Toulouse, France.

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: 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.



I have recently submitted PhD thesis on “QoS-aware Application Management in Fog Computing Environments”. My publications have already attracted 680+ citations and helped me to attain h-index 10 within a very short period.

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>

Here are my papers published in 2019:

1. 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), 433-466pp, ISBN: 978-111-95-2498-4, Wiley Press, New York, USA, January 2019.
2. Adel Nadjaran Toosi, Redowan Mahmud, Qinghua Chi, and Rajkumar Buyya, [Management and Orchestration of Network Slices in 5G, Fog, Edge and Clouds](#), Fog and Edge Computing: Principles and Paradigms, R. Buyya and S. Srirama (eds), 79-102pp, ISBN: 978-111-95-2498-4, Wiley Press, New York, USA, January 2019.
3. Redowan Mahmud, Kotagiri Ramamohanarao, and Rajkumar Buyya, [Latency-aware Application Module Management for Fog Computing Environments](#), ACM Transactions on Internet Technology (TOIT), Volume 19, No. 1, Article 9, Pages: 1-21, ISSN:1533-5399, ACM Press, New York, USA, March 2019.
4. Shreshth Tuli, Redowan Mahmud, Shikhar Tuli, and Rajkumar Buyya, [FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing](#), Journal of Systems and Software (JSS), Volume 154, Pages: 22-36, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, August 2019.
5. Redowan Mahmud, Satish Narayana Srirama, Ramamohanarao Kotagiri, and Rajkumar Buyya, [Quality of Experience \(QoE\)-aware Placement of Applications in Fog Computing Environments](#), Journal of Parallel and Distributed Computing (JPDC), Volume 132, Pages: 190-203, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, October 2019.
6. Redowan Mahmud, Kotagiri Ramamohanarao, and Rajkumar Buyya, [Edge Affinity-based Management of Applications in Fog Computing Environments](#), 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.

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 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 anomaly detection, Security data analytics, cloud performance management and optimization techniques. I submitted my PhD thesis in July 2019 and its formal details are:

Sara Kardani Moghaddam, [Anomaly-aware Management of Cloud Computing Resources](#), Ph.D. Thesis, The University of Melbourne, Australia, July 2019.



Here are my papers published in 2019:

1. Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, [ACAS: An Anomaly-based Cause Aware Auto-Scaling Framework for Clouds](#), Journal of Parallel and Distributed Computing (JPDC), Volume 126, Pages: 107-120, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, April 2019.
2. Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, [Performance-Aware Management of Cloud Resources: A Taxonomy and Future Directions](#), ACM Computing Surveys, Volume 52, No. 4, Article No. 84, Pages: 1-37, ISSN 0360-0300, ACM Press, New York, USA, September 2019.
3. Sara Kardani Moghaddam, Rajkumar Buyya, and Ramamohanarao Kotagiri, [Performance Anomaly Detection Using Isolation-Trees in Heterogeneous Workloads of Web Applications in Computing Clouds](#), Concurrency and Computation: Practice and Experience (CCPE), Volume 31, No. 20, Pages: 1-17, ISSN: 1532-0626, Wiley Press, New York, USA, October 2019.

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 data-driven resource management techniques to optimize the energy consumption of cloud data centers. Please find the recent co-authored research works below:



- **Shashikant Ilager**, Rajeev Muralidhar, Rammohanrao Kotagiri 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), Melbourne, Australia, May 11-14, 2020.
- **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 31, No. 17, Pages: 1-15, ISSN: 1532-0626, Wiley Press, New York, USA, September 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.
- **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 (in review).
- Shreshth Tuli, **Shashikant Ilager**, Kotagiri Ramamohanarao, and Rajkumar Buyya, *Stochastic Dynamic Scheduling using Deep Learning for Fog Computing Environments*, IEEE Transactions on Mobile Computing (in review).

For more information, kindly visit the following pages.

Website: <http://www.shashikantilager.com>

LinkedIn: <https://www.linkedin.com/in/shashikantilager/>

Member Self Profile: Tawfiq 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 2019, I have published a journal paper. In addition, another journal paper is currently under review. Here is a list of publications I have finished during the first 3 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. [PDF](#)
- M. T. Islam and R. Buyya, "Resource management and scheduling for big data applications in cloud computing environments," *Handbook of Research on Cloud Computing and Big Data Applications in IoT*, 2019. [PDF](#)
- M. T. Islam, S. N. Srirama, S. Karunasekera, and R. Buyya, "Cost-efficient dynamic scheduling of big data applications in apache spark on cloud," *Journal of Systems and Software (JSS)*, vol. 162, 2020. [PDF](#)
- M. T. Islam, H. Wu, S. Karunasekera, and R. Buyya, "SLA-based Scheduling of Spark Jobs in Hybrid Cloud Computing Environments", *IEEE Transactions on Parallel and Distributed Systems (TPDS)* [Under Review].

Currently, I am working on the following project:

- SLA-based Adaptive Resource Management using Deep Reinforcement Learning

If you are interested in my research, please do not hesitate to contact me:

GitHub: <https://github.com/tawfiqul-islam>

Linkedin: <https://www.linkedin.com/in/tawfiqul-islam-1968a721/>

Email: muhammedi@student.unimelb.edu.au

Google Scholar:

<https://scholar.google.com.au/citations?user=TVzqs2YAAAAJ&hl=en>

Member Self Profile: Tianzhang He

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

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

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



Projects:

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

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

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

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

[3] SLA-Aware Multiple Migration Planning and Scheduling in SDN-NFV-enabled Clouds (*under review*).

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

Member Self Profile: Zhiheng Zhong (David)

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.



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.



In the first year of my PhD career, I was awarded the Rowden White Scholarship, a prestigious scholarship provided by the University of Melbourne to talented, high quality PhD students. Besides, our paper “A fog-driven dynamic resource allocation technique in ultra-dense femtocell networks” is published in the “Journal of network and Computer Applications”. The second year started with acceptance of my second research “An Application Placement Technique for Concurrent IoT Applications in Edge and Fog Computing Environments” article in “IEEE Transactions on Mobile Computing”.

My research interests include IoT, Fog/Edge Computing, Distributed Systems, Wireless Communication, Optimization, and Data Analytics. Currently in the second year of my PhD career, I am investigating the concepts of Fog computing and IoT.

Further information can be found in 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: 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", Accepted, ACM Computing Surveys.
4. MH Hilman, MA Rodriguez, R Buyya, "Resource-sharing Policy in Multi-tenant Workflow as a Service Platform", Under Review, ACM Transaction on Computer Systems.

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: 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 scheduling policies in Fog computing environments, specially focusing on microservices-based IoT applications.



In 2019, I published one paper based on my PhD research,

- Samodha Pallewatta, Vassilis Kostakos, and Rajkumar Buyya. 2019. Microservices-based IoT Application Placement within Heterogeneous and Resource Constrained Fog Computing Environments. In Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing (UCC'19). Association for Computing Machinery, New York, NY, USA, 71–81.

For more information please refer,

<https://linkedin.com/in/samodha-pallewatta>

Member Self Profile: Amanda Jayanetti

I joined CLOUDS lab to 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.

In the first year of my PhD, I have worked on the following publication,

- Jayanetti, A. and Buyya, R., 2019, December. J-OPT: A Joint Host and Network Optimization Algorithm for Energy-Efficient Workflow Scheduling in Cloud Data Centers. In *Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing* (pp. 199-208).



Member Self Profile: Amin Shahraki

I joined the CLOUDS Laboratory in August 2019 as a visiting student for about 6 months. I get back to Norway, University of Oslo, to Complete my PhD on Feb. 2020. During my visit, I have been working on resource management, topology management and edge computing in massive-scale IoT networks.

I am currently working on clustering techniques and resource management techniques in massive-scale IoT networks that mimic ad hoc networks to establish self-healing network infrastructures. In addition, I work on highly heterogeneous IoT networks and managing resources, 5G-IoT cellular networks, topology management of IoT networks and mist computing. I also work on Network behavior analysis techniques to provide QoS for massive-scale IoT networks. My focus is on clustering techniques and their applications to organize IoT networks and support QoS. Also, I work on using clustering techniques to apply different paradigms like Blockchain, Computing paradigms and SDN to IoT networks.



For further details about my current status, research interest, open source projects, and recent publication, please visit my LinkedIn: [Click here](#)

Member Self Profile: Rajeev Muralidhar

I joined the CLOUDS Laboratory in Sep. 2019 as a part time PhD student. I work full time at Amazon Web Services as a Principal Solutions Architect in the area of IOT, AI/ML/edge computing.

I have worked in the industry for over 20 years now, and have a background in several technology areas - energy efficient systems, IOT/M2M devices/platforms, energy efficient AI/ML, software-defined networks, networking and supercomputing/high performance computing. During 2018-2019, I was a Principal IOT Architect in Telstra's Mobility and IOT Group. Prior to this, I spent 18 years at Intel across multiple locations in US and India. As Principal Engineer in Intel's Client & IOT Architecture Group, I had the privilege to work with some terrific and smart people delivering several generations of energy efficiency technologies for several industry defining products like the Amazon Echo Show, Google Nexus Player, Google Glass, TAG Hauer smartwatch, and several others. I also spent several years in Intel Architecture and Research Labs during 2000-2005 working on the foundations of software-defined networking, network processor stacks, and protocols, standards and architectures for quality of service in the internet. During this time, I had the opportunity to actively participate in, and drive several industry standards/consortiums - networking standards at the IETF and Network Processing Forum, NANOG, low power standards at IEEE, and some key components of the Linux power and thermal management subsystems.



I have a Bachelor of Eng from NIT, Surathkal (India) and Master of Science from Rutgers University, both in Computer Science. I have about 30 US patents (granted) and have published over 25 conference/journal papers.

I like collaborating with researchers in academia on forward looking problems. I am a Senior Member of the IEEE and I am part of the steering / program committee of the IEEE International Conf on High Performance and Big Data Computing. I like to work with, and mentor graduate/undergraduate students and early career professionals.

In my free time, I love running (during my fitter days, I did some high altitude ultramarathons in the Himalayas and elsewhere), spending time with my family/friends, and I read a lot on many diverse subjects.

Member Self Profile: Zhicheng Cai

I joined the CLOUDS Laboratory in September of 2019 as a Visiting Scholar. I'm currently also an Associate Professor of Nanjing University of Science and Technology, China. And I completed my PHD in 2015 at Southeast University, China.

In 2019, I'm working on resource management in Cloud Computing systems, including developing feedback and feedforward control methods to minimize resource rental costs of Web applications while guaranteeing Qos and developing scheduling algorithms to minimize rental costs or execution times of workflow applications.

In 2019, I and coauthors have got the following papers published:

- [1] **Zhicheng Cai** (#)(^{*}); Xiaoping Li; Ruben Ruiz, Resource Provisioning for Task-Batch Based Workflows with Deadlines in Public Clouds, IEEE Transactions on Cloud Computing, 2019.9 , 7(3): 814~826.
- [2] Duan Liu(#); **Zhicheng Cai**(^{*}); Yifei Lu, Spot Price Prediction Based Dynamic Resource Scheduling for Web Applications, 2019 Seventh International Conference on Advanced Cloud and Big Data (CBD), Suzhou, 2019.9.21-2019.9.22.
- [3] Pengfei Sun(#); **Zhicheng Cai**(^{*}); Duan Liu, Budget Constraint Bag-of-Task Based Workflow Scheduling in Public Clouds, 14th CCF Conference on Computer Supported Cooperative Work and Social Computing, ChineseCSCW 2019, Kunming, China, 2019.8.16-2019.8.18.

For more information, please visit:

ResearchGate: https://www.researchgate.net/profile/Zhicheng_Cai2



Visitor Self Profile: Linna Ruan

I joined the CLOUDS Laboratory in Sep. 2019 as a visiting student researching resource allocation and service computation offloading in edge-cloud environment. I will back to the Beijing University of Posts and Telecommunications (BUPT, China) in Sep. 2020 and complete my PhD.

I am currently working on edge and cloud cooperation and its application in smart grid. Edge AI is envisioned as a useful tool to predict electricity demand. The function can be realized with edge server and attract more people to join demand response which can drive people to cut or shift demand. I focus on the interaction mechanism design between consumer and supplier and also think about virtual resource allocation with the aim of guaranteeing response time and promote consumers to achieve high participation in demand response process as soon as possible.

I have a bachelor's degree in Communication Engineering from Beijing Information Science and Technology University in China. Now, I am taking successive postgraduate and doctoral program since 2016 in BUPT.



Visitor Self Profile: Xiaogang Wang

I joined the CLOUDS lab in September 2019 as a visiting scholar under the supervision of Professor Rajkumar Buyya. Before came to Australia, I obtained my Ph.D. degree in computer science and technology from Shanghai Jiao Tong University, China. I am currently an associate professor with the School of Electronics and Information, Shanghai Dianji University, China. I have published or been accepted over 20 papers in some journals and conferences such as the IEEE Transactions on services computing, the Journal of Systems and Software, WI-IAT, APSCC, CSCWD, and ICSAI. My current research interests include cloud resource prediction, provisioning and scheduling, service computing, big data analysis and multi-agent systems. Professor Rajkumar Buyya is a very passionate and inspired [tutor](#), he often gives us some meaningful research guidance at the weekly group meeting, and I also obtains a lot of valuable advices.



Recently, I submitted a paper, and another paper is in press during my stay in CLOUDS Lab. If you have interest, please find them below:

- Xiaogang Wang, Rajkumar Buyya, Jian Cao, Dingyu Yang, Zhen Qin. Online Cloud Resource Prediction via Scalable Window Waveform Sampling on Classified Workloads. IEEE Transactions on Parallel and Distributed Systems. (Submitted).
- Xiaogang Wang, Jian Cao, Yang Xiang. OSPN: Optimal Service Provisioning with Negotiation for Bag-of-Tasks Applications. IEEE Transactions on Services Computing, DOI: 10.1109/TSC.2017.2787707 (In Press)

Member Self Profile: Dongcheng Zhao

I joined the CLOUDS Lab as a visiting Ph.D. in Oct 2019, the visit will last about 1 year.

I'm pursuing his Ph.D. degree in Communication and Information System at University of Electronic Science and Technology of China. My research interests include network function virtualization, Cloud computing, fog computing and 5G mobile networks.

Below you can find my selected publications related to my recent publications:

1. **Dongcheng Zhao**, Dan Liao, Gang Sun, and Shizhong Xu. Towards Resource-Efficient Service Function Chain Deployment in Cloud-Fog Computing. IEEE Access, 6(1), pp.66754-66766, 2018.
2. **Dongcheng Zhao**, Gang Sun, Dan Liao, Shizhong Xu, and Victor Chang. Mobile-aware Service Function Chain Migration in Cloud-Fog Computing. Future Generation Computer Systems, 96, pp.591-604, 2019.
3. **Dongcheng Zhao**, Jing Ren, Rongping Lin, Shizhong Xu and Victor Chang. On Orchestrating Service Function Chains in 5G Mobile Network. IEEE Access, 7(1), pp. 39402-39416, 2019.



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: Deed Learning, ECG Monitoring & Analysis, Data Mining & Business Analytics, and Brain Imaging (Dartmouth Medical School).

Future Research is Driven By:

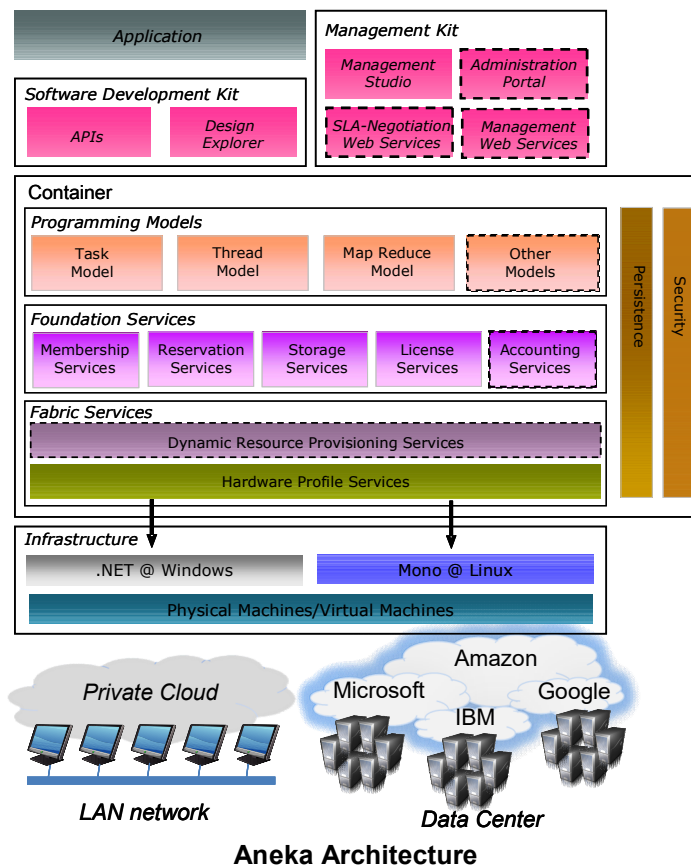
[A Manifesto for Future Generation Cloud Computing: Research Directions for the Next Decade,](#)

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.

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.

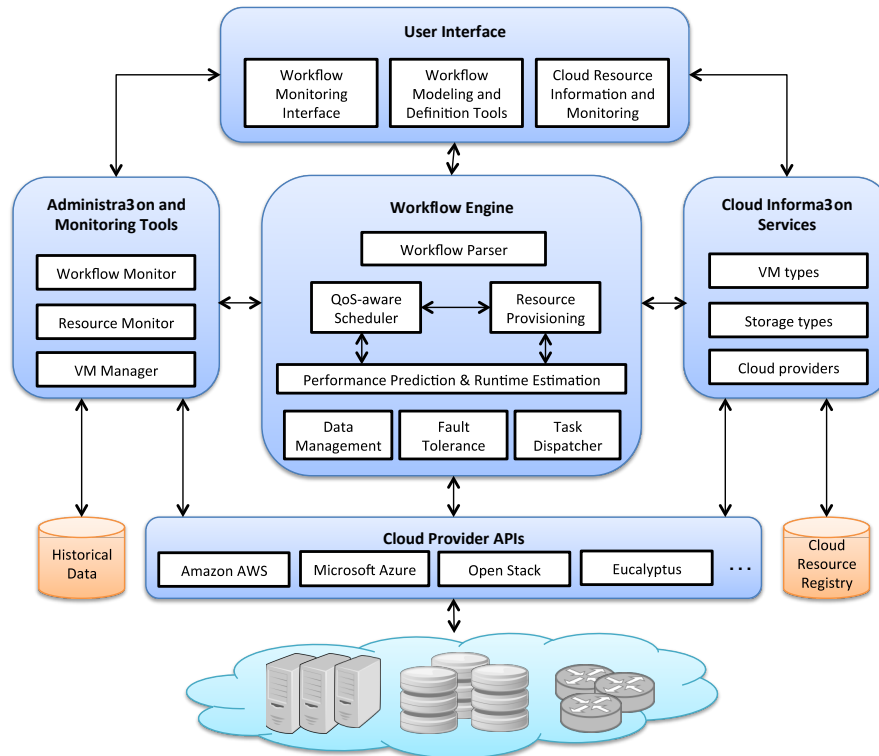


Fig. 1: Architecture of QoS-based workflow management and resource allocation system.

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, [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, 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.
- 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.
- 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.
- 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.

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, TianZhang He and Rajkumar Buyya, [CloudSimSDN-NFV: Modeling and Simulation of Network Function Virtualization and Service Function Chaining in Edge Computing Environments](#), Software: Practice and Experience (SPE), Volume 49, No. 12, Pages: 1748-1764, ISSN: 0038-0644, Wiley Press, New York, USA, December 2019.

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

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

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

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

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

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.
- Redowan Mahmud, Satish Narayana Srirama, Ramamohanarao Kotagiri, and Rajkumar Buyya, [Quality of Experience \(QoE\)-aware Placement of Applications in Fog Computing Environments](#), *Journal of Parallel and Distributed Computing (JPDC)*, Volume 132, Pages: 190-203, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, October 2019.

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

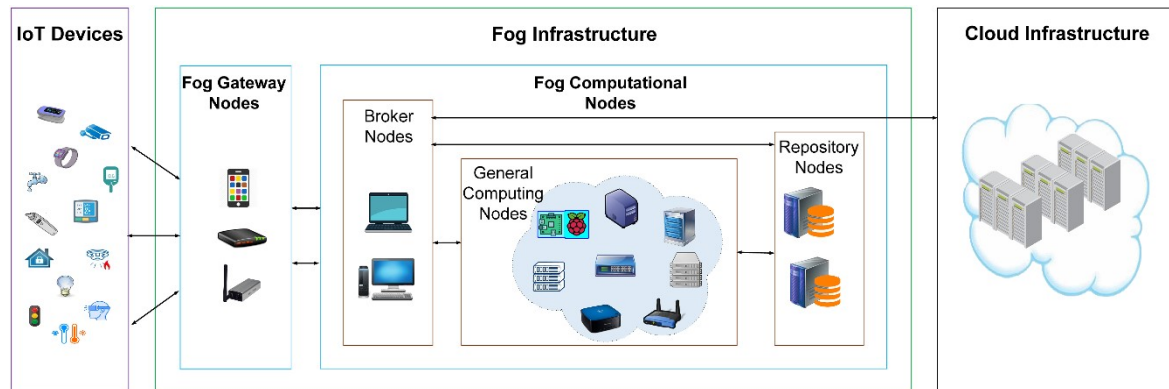
Web: <https://github.com/Cloudslab/FogBus>

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 and services providers. Based on FogBus, we have also developed a prototype application system for Sleep Apnea analysis in integrated IoT-Fog-Cloud environment. Furthermore, for ensuring data security, FogBus implements Blockchain, encryption and digital signature techniques.



References:

- [1] Shreshth Tuli, Redowan Mahmud, Shikhar Tuli, and Rajkumar Buyya, [FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing](#), Journal of Systems and Software (JSS), Volume 154, Pages: 22-36, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, August 2019.
- [2] Shreshth Tuli, Nipam Basumatary, and Rajkumar Buyya, [EdgeLens: Deep Learning based Object Detection in Integrated IoT, Fog and Cloud Computing Environments](#), Proceedings of the 4th IEEE International Conference on Information Systems and Computer Networks (ISCON 2019, IEEE Press, USA), Mathura, India, November 21-22, 2019.
- [3] Riccardo Mancini, Shreshth Tuli, Tommaso Cucinotta, and Rajkumar Buyya, [iGateLink: A Gateway Library for Linking IoT, Edge, Fog and Cloud Computing Environments](#), Proceedings of the International Conference on Intelligent and Cloud Computing (ICICC-2019, Springer, Germany), Bhubaneswar, India, December 16-17, 2019.

9. Moments with Visitors, Colleagues and International Hosts



A snap of CLOUDS lab members taken during Jay's PhD completion seminar.



January 10-13, 2019: International Conference on Big Data and Smart Computing, Singaraja, Bali, Indonesia



With Professor Inderveer Chana and seminar attendees at Thapar University (April 2019)



International Conference on High Performance Computing & Simulation (HPCS 2019), Dublin, Ireland (July 15 – 19, 2019)



With Prof Gordon Blair during visit to Lancaster University, UK (July 2019)



With Prof Dr. Rami Bahsoon during visit to the University of Birmingham, UK (July 2019)



Master Students at UniMelb (Oct 2019)



Nirma University (Dec. 2019)