Cloud Computing and Distributed Systems (CLOUDS) Laboratory

www.cloudbus.org

Annual Report - 2020

School of Computing and Information Systems

Faculty of Engineering and Information Technology

The University of Melbourne, Australia

1. Director's Message

I am pleased to report on the key activities and outcomes of **Clou**d Computing and **D**istributed **S**ystems (CLOUDS) Laboratory at the University of Melbourne, Australia during the academic year 2020, 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 2020 are:

- The Lab successfully hosted ARC research projects (Discovery and Linkage Infrastructure Projects) along with hosting two new research projects.
- Members of the CLOUDS Lab have authored 58 publications, which include 36 journal papers and 12 conference papers.
- Three of our papers received "Best Paper Awards" from IEEE/ACM and Elsevier.
- The Lab's flagship Cloudbus Project has released various new modules for Aneka, CloudSim, iFogSim, and Fogbus. iFogSim, building on CloudSim, has emerged as a de-facto toolkit for modelling and simulation of Fog and Edge computing environments. It has been used by several researchers in academia and industries around the world.
- Members have presented over 26 invited talks that include 19 keynotes delivered at international conferences/seminars held in Australia, India, Singapore, and China.
- The Lab successfully hosted research activities of over 25 scholars, which include 16 PhD students and 3 Research Fellows.
- In 2020 alone, our papers have attracted over 10700 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, and Norway.
- A list of the world's top 2% researchers complied by Stanford University after assessing scientists worldwide for research carried out over their careers across all disciplines ranks us as **#1 for citation impact** during the single calendar year 2019 and #2 for career-long citation impact up until the end of 2019 in Distributed Computing area.
- Members of the Lab have led community efforts such as (a) the organisation of conferences (e.g., CCGrid 2020 in Australia) and (b) Editor-In-Chief of Journal of Software: Practice and Experience, which was established 50+ years ago.

The Lab is always looking for talented, motivated, and dedicated "young" students and researchers to join its team. Please feel free to contact me with your ideas!

Sincerely yours,

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

2. The Team

Director:

- Professor Rajkumar Buyya

Research Staff/Academics:

- Dr. Adel Toosi
- Dr. Maria Rodriguez
- Dr. Redowan Mahmud

PhD Students

- Mr. Muhammad H. Hilman
- Ms. Imairi Eitiveni
- Mr. Muhammed Tawfiqul
- Mr. Carlos Gomez, 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
- Ms. Anupama Mampage
- Mr. Jie Zhao
- Mr. Ming Chen

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

International Visitors
- 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-Sept. 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.
- D. Tao, B. Vucetic, R. Kotagiri, E. Nebot, X. Lin, Y. Gao, M. Bennamoun, R. Buyya, T. Baldwin, S. Williams, J. Yuan, and M. Pagnucco, "Whopping Volta GPU Cluster Transforming Artificial Intelligence Research", Linkage Infrastructure, Equipment and Facilities (LIEF) grant, Australian Research Council (ARC), Australia, 2020. Amount: $900,000.

Other National Grants

- Soumya K. Ghosh (Indian lead) and Rajkumar Buyya (Australian lead), "Spatial Cloud Federation: Orchestration of Multiple Spatial Clouds for Efficient Provisioning of Spatial Services", SPARC (Scheme for Promotion of Academic and Research Collaboration), Ministry of Human Resource Development, Government of India, 2019-2022, Amount: Indian Rupees 52.8 Lakh (52,80,000).
- R. Buyya, M. Rodriguez, V. Sivaraman, A. Toosi, and L. Sciacca. Distributed Applications over Programmable Networks. Next Generation Technologies Fund, Department of Defence, Australia, 2020. Amount: $100,000.

Industry and Melbourne University Grants

- M. Vrakopoulou, C. Chan, R. Buyya, and L. Sciacca, "Novel Methods to Monitor, Track and Efficiently Manage Power within Racks", Lockheed Martin, 2020. Amount: A$75,000.

4. Publications

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

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

Books/Proceedings Edited

1. Bibudhendu Pati, Chhabi Rani Panigrahi, Rajkumar Buyya, Kuan-Ching Li (editors), Advanced Computing and Intelligent Engineering: Proceedings of the 3rd International Conference (ICACIE 2018), ISBN: 978-981-15-1080-9, Springer Nature, Singapore, March 2020.
2. Harvinder Singh Saini, Rishi Sayal, Rajkumar Buyya, and Govardhan Aliseri (editors), Innovations in Computer Science and Engineering: Proceedings of 7th ICICSE, ISBN: 978-981-15-2042-6, Springer Nature, Singapore, March 2020.
3. Laurent Lefevre, Carlos A. Varela, George Pallis, Adel N. Toosi, Omer Rana, and Rajkumar Buyya, Proceedings of the 20th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2020, May 17-20, 2020, Melbourne, Australia), ISBN 978-1-7281-6095-5, IEEE CS Press, Los Alamitos, CA, USA, 2020.
4. Debahuti Mishra, Rajkumar Buyya, Prasant Mohapatra, and Srikanta Patnaik (eds), Intelligent and Cloud Computing: Proceedings of ICICC 2019, Volume 2, ISBN 978-981-15-6201-3, Springer Nature, Singapore, August 2020.

Book Chapters

5. Yaser Mansouri and Rajkumar Buyya, Data Access Management System in Azure Blob Storage and AWS S3 Multi-Cloud Storage Environments, Handbook of Research on Intrusion Detection Systems, B. Gupta and S. Srinivasagopalan (eds), 130-147pp, ISBN13: 9781799822424, IGI Global, Hershey, PA, USA, February 2020.
6. Maria A. Rodriguez, Rajkumar Buyya, Containers Orchestration with Cost-Efficient Autoscaling in Cloud Computing Environments, Handbook of Research on Multimedia Cyber Security, B. Gupta and D. Gupta (eds), 190-213pp, ISBN13: 9781799827016, IGI Global, Hershey, PA, USA, April 2020.
7. Raj Gaire, Chigulapalli Sriharsha, Deepak Puthal, Hendra Wijaya, Jongkil Kim, Prateeksha Keshari, Rajiv Ranjan, Rajkumar Buyya, Ratan K. Ghosh, RK Shyamasundar and Surya Nepal, Internet of Things (IoT) and Cloud Computing Enabled Disaster Management, Handbook of Integration of Cloud Computing, Cyber Physical Systems and Internet of Things, R. Ranjan, K. Mitra, P. Prakash Jayaraman, L. Wang, and A.Y. Zomaya (eds.), 273-298pp, ISBN: 978-3-030-43794-7, Springer, Switzerland, August 2020.

Journal Editorials

8. Rajiv Ranjan, Massimo Villari, Haiying Shen, Omer Rana, and Rajkumar Buyya, Software tools and techniques for fog and edge computing, Software: Practice and Experience, Volume 50, Number 5, Pages: 473-475, ISSN: 0038-0644, Wiley Press, New York, USA, May 2020.

9. Blesson Varghese, Marco Netto, Ignacio M. Llorente, and Rajkumar Buyya, New Generation Cloud Computing, Software: Practice and Experience, Volume 50, Number 6, Pages: 803-804, ISSN: 0038-0644, Wiley Press, New York, USA, June 2020.

Journal Papers

10. Redowan Mahmud, Satish Narayana Srirama, Kotagiri Ramamohanarao, and Rajkumar Buyya, Profit-aware Application Placement for Integrated Fog-Cloud Computing Environments, Journal of Parallel and Distributed Computing (JPDC), Volume 135, Pages: 177-190, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, January 2020.

11. Minxian Xu and Rajkumar Buyya, Managing Renewable Energy and Carbon Footprint in Multi-cloud Computing Environments, Journal of Parallel and Distributed Computing (JPDC), Volume 135, Pages: 191-202, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, January 2020.

12. Shridhar Domanal, Ram Mohana Reddy Guddeti, and Rajkumar Buyya, A Hybrid Bio-Inspired Algorithm for Scheduling and Resource Management in Cloud Environment, IEEE Transactions on Services Computing (TSC), Volume 13, Number 1, Pages: 3-15, ISSN: 1939-1374, IEEE Computer Society Press, USA, January-February 2020.

13. Chi-Ting Chen, Ling-Ju Hung, Sun-Yuan Hsieh, Rajkumar Buyya, and Albert Y. Zomaya, Heterogeneous Job Allocation Scheduler for Hadoop MapReduce Using Dynamic Grouping Integrated Neighboring Search, IEEE Transactions on Cloud Computing (TCC), Volume 8, Number 1, Pages: 193-206, ISSN: 2168-7161, IEEE Computer Society Press, USA, January-March 2020.

14. Pejman Goudarzi, Abolfazl Ghassemi, Mohammad R. Mirsarraf, and Rajkumar Buyya, Joint Energy-QoE Efficient Content Delivery Networks Using Real-Time Energy Management, IEEE Systems Journal, Volume 14, Number 1, Pages: 927-938, ISSN: 1932-8184, IEEE Press, New York, USA, March 2020.

15. Shreshth Tuli, Nipam Basumatary, Sukhpal Singh Gill, Mohsen Kahani, Rajesh Chand Arya, Gurpreet Singh Wander, and Rajkumar Buyya, HealthFog: An Ensemble Deep Learning based Smart Healthcare System for Automatic Diagnosis of Heart Diseases in Integrated IoT and Fog Computing Environments, Future Generation Computer Systems (FGCS), Volume 104, Pages: 187-200, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, March 2020.

16. Sukhpal Singh, Inderveer Chana and Rajkumar Buyya, Agri-Info: Cloud Based Autonomic System for Delivering Agriculture as a Service, Internet of Things: Engineering Cyber Physical Human Systems, Volume 9, Pages: 1-16, ISSN 2542-6605, Elsevier Press, Amsterdam, The Netherlands, March 2020.

17. Zhiheng Zhong and Rajkumar Buyya, A Cost-efficient Container Orchestration Strategy in Kubernetes-based Cloud Computing Infrastructures with Heterogeneous Resources, ACM Transactions on Internet Technology (TOIT), Volume 20, No. 2, Article 15, Pages: 1-24, ISSN: 1533-5399, ACM Press, New York, USA, April 2020.

18. Jaydeep Das, Anwesha Mukherjee, Soumya K. Ghosh, and Rajkumar Buyya, Spatio-Fog: A Green and Timeliness-oriented Fog Computing Model for Geospatial Query Resolution, Simulation Modelling Practice and Theory, Volume 100, Pages: 1-23, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, April 2020.

19. Dawei Sun, Shang Gao, Xunyun Liu, Fengyun Li, and Rajkumar Buyya, Performance-Aware Deployment of Streaming Applications in Distributed Stream Computing Systems,

International Journal of Bio-Inspired Computation, Volume 15, No. 1, Pages: 52-62, ISSN: 1758-0366, Inderscience Publishers, Geneva, Switzerland, April 2020.

20. Caesar Wu, Rajkumar Buyya, and Kotagiri Ramamohanarao, Modeling Cloud Business Customers' Utility Functions, Future Generation Computer Systems (FGCS), Volume 105, Pages: 737-753, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, April 2020.

21. Muhammed Tawfiqul Islam, Satish N. Srirama, Shanika Karunasekera, and Rajkumar Buyya, Cost-efficient Dynamic Scheduling of Big Data Applications in Apache Spark on Cloud, Journal of Systems and Software (JSS), Volume 162, Pages: 1-14, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, April 2020.

22. Wendy Yanez, Redowan Mahmud, Rami Bahsoon, Yuqun Zhang, and Rajkumar Buyya, Data Allocation Mechanism for Internet-of-Things Systems With Blockchain, IEEE Internet of Things Journal, Volume 7, Number 4, Pages: 3509-3522, ISSN: 2327-4662, IEEE Computer Society Press, USA, April 2020.

23. Muhammad Hilman, Maria Rodriguez, and Rajkumar Buyya, Multiple Workflows Scheduling in Multi-tenant Distributed Systems: A Taxonomy and Future Directions, ACM Computing Surveys, Volume 53, No. 1, Article No. 10, Pages: 1-39, ISSN: 0360-0300, ACM Press, New York, USA, May 2020.

24. Shreshth Tuli, Rajinder Sandhu, and Rajkumar Buyya, Shared Data-Aware Dynamic Resource Provisioning and Task Scheduling for Data Intensive Applications on Hybrid Clouds using Aneka, Future Generation Computer Systems (FGCS), Volume 106, Pages: 595-606, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, May 2020.

25. Shweta Saharan, Gaurav Somani, Gaurav Gupta, Robin Verma, Manoj Singh Gaur, and Rajkumar Buyya, QuickDedup: Efficient VM Deduplication in Cloud Computing Environments, Journal of Parallel and Distributed Computing (JPDC), Volume 139, Pages: 18-31, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, May 2020.

26. Sun-Yuan Hsieh, Cheng-Sheng Liu, Rajkumar Buyya, and Albert Y. Zomaya, Utilization-Prediction-aware Virtual Machine Consolidation Approach for Energy-Efficient Cloud Data Centers, Journal of Parallel and Distributed Computing (JPDC), Volume 139, Pages: 99-109, ISSN: 0743-7315, Elsevier Press, Amsterdam, The Netherlands, May 2020.

27. Sukhpal Singh Gill and Rajkumar Buyya, Failure Management for Reliable Cloud Computing: A Taxonomy, Model, and Future Directions, Computing in Science and Engineering (CiSE), ISSN 1521-9615, Volume 22, Issue 3, Pages: 52-63, IEEE Computer Society Press and American Institute of Physics, USA, May 2020.

28. Jialei Liu, Shangguang Wang, Ao Zhou, Fangchun Yang, and Rajkumar Buyya, Availability-aware Virtual Cluster Allocation in Bandwidth-Constrained Datacenters, IEEE Transactions on Services Computing (TSC), Volume 13, Number 3, Pages: 425-436, ISSN: 1939-1374, IEEE Computer Society Press, USA, May/June 2020.

29. Xunyun Liu and Rajkumar Buyya, Resource Management and Scheduling in Distributed Stream Processing Systems: A Taxonomy, Review, and Future Directions, ACM Computing Surveys, Volume 53, No. 3, Article No. 50, Pages: 1-41, ISSN: 0360-0300, ACM Press, New York, USA, June 2020.

30. Mohammadreza Razian, Mohammad Fathian, and Rajkumar Buyya, ARC: Anomaly-aware Robust Cloud-integrated IoT Service Composition based on Uncertainty in Advertised Quality of Service Values, Journal of Systems and Software (JSS), Volume 164, Pages: 1-20, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, June 2020.

31. Jitendra Kumar, Ashutosh Kumar Singh, and Rajkumar Buyya, Ensemble Learning based Predictive Framework for Virtual Machine Resource Request Prediction, Neurocomputing, Volume 397, Pages: 20-30, ISSN: 0925-2312, Elsevier Press, Amsterdam, The Netherlands, July 2020.

32. Moumita Mishra, Sayan Kumar Roy, Anwesha Mukherjee, Debashis De, Soumya K. Ghosh, and Rajkumar Buyya, An Energy-Aware Multi-Sensor Geo-Fog Paradigm for

Mission Critical Applications, Journal of Ambient Intelligence and Humanized Computing, Volume 11, Number 8, Pages: 3155-3173, ISSN: 1868-5137, Springer Science+Business Media, Berlin, Germany, August 2020.

33. Sukhpal Singh Gill, Shreshth Tuli, Adel Nadjaran Toosi, Felix Cuadrado, Peter Garraghan, Rami Bahsoon, Hanan Lutfiyya, Rizos Sakellariou, Omer Rana, Schahram Dustdar, and Rajkumar Buyya, ThermoSim: Deep Learning based Framework for Modeling and Simulation of Thermal-aware Resource Management for Cloud Computing Environments, Journal of Systems and Software (JSS), Volume 166, Pages: 1-20, ISSN: 0164-1212, Elsevier Press, Amsterdam, The Netherlands, August 2020.

34. Shreya Ghosh, Soumya K. Ghosh, and Rajkumar Buyya, MARIO: A Spatio-temporal Data Mining Framework on Google Cloud to Explore Mobility Dynamics from Taxi Trajectories, Journal of Network and Computer Applications (JNCA), Volume 164, Pages: 1-17, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, August 2020.

35. Geeta C M, Usharani Rathod, Shreyas Raju R G, Raghavendra S, Rajkumar Buyya, Venugopal K R, S S Iyengar, and L M Patnai, CRUPA: Collusion Resistant User Revocable Public Auditing of Shared Data in Cloud, Journal of Cloud Computing: Advances, Systems and Applications, Volume 9, Pages: 1-18, ISSN: 2192-113X, Springer Nature, UK, August 2020.

36. Redowan Mahmud, Kotagiri Ramamohanarao, and Rajkumar Buyya, Application Management in Fog Computing Environments: A Taxonomy, Review and Future Directions, ACM Computing Surveys, Volume 53, No. 4, Article No. 88, Pages: 1-43, ISSN: 0360-0300, ACM Press, New York, USA, September 2020.

37. Faizan Murtaza, Adnan Akhunzada, Saif ul Islam, Jalil Boudjadar, and Rajkumar Buyya, QoS-Aware Service Provisioning in Fog Computing, Journal of Network and Computer Applications (JNCA), Volume 165, Pages: 1-14, ISSN: 1084-8045, Elsevier, Amsterdam, The Netherlands, September 2020.

38. Dawei Sun, Shang Gao, Xunyun Liu, Xindong You, and Rajkumar Buyya, Dynamic Redirection of Real-Time Data Streams for Elastic Stream Computing, Future Generation Computer Systems (FGCS), Volume 112, Pages: 193-208, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, November 2020.

39. Niloofar Gholipour, Ehsan Arianyan, and Rajkumar Buyya, A novel energy-aware resource management technique using joint VM and container consolidation approach for green computing in cloud data centers, Simulation Modelling Practice and Theory, Volume 104, Pages: 1-15, ISSN: 1569-190X, Elsevier Press, Amsterdam, The Netherlands, November 2020.

40. Redowan Mahmud, Adel N. Toosi, Kotagiri Ramamohanarao, and Rajkumar Buyya, Context-aware Placement of Industry 4.0 Applications in Fog Computing Environments, IEEE Transactions on Industrial Informatics, Volume 16, Number 11, Pages: 7004-7013, ISSN: 1551-3203, IEEE Press, New Jersey, USA, November 2020.

41. Mohammed Khalaf, Haya Alaskar, Abir Jaafar Hussain, Thar Baker, Zakaria Maamar, Rajkumar Buyya, Panos Liatsis, Wasiq Khan, Hissam Tawfik, Dhiya Al-Jumeily, IoT-enabled Flood Severity Prediction via Ensemble Machine Learning Models, IEEE Access, Volume 8, Pages: 70375-70386, ISSN: 2169-3536, IEEE Press, New Jersey, USA, December 2020.

42. Zhicheng Cai, Duan Liu, Yifei Lu, and Rajkumar Buyya, Unequal-Interval based Loosely Coupled Control Method for Auto-scaling Heterogeneous Cloud Resources for Web Applications, Concurrency and Computation: Practice and Experience (CCPE), Volume 32, No. 23, Pages: 1-16, ISSN: 1532-0626, Wiley Press, New York, USA, December 2020.

43. Sukhpal Singh, Inderveer Chana, and Rajkumar Buyya, STAR: SLA-aware Autonomic Management of Cloud Resources, IEEE Transactions on Cloud Computing (TCC), Volume 8, Number 4, Pages: 1040-1053, ISSN: 2168-7161, IEEE Computer Society Press, USA, Oct.-Dec. 2020.

44. Shreya Ghosh, Anwesha Mukherjee, Soumya K. Ghosh, and Rajkumar Buyya, Mobi-IoST: Mobility-aware Cloud-Fog-Edge-IoT Collaborative Framework for Time-Critical Applications, IEEE Transactions on Network Science and Engineering (TNSE), Volume 7,

Number 4, Pages: 2271-2285, ISSN:2327-4697, IEEE Press, New Jersey, USA, Oct.-Dec. 2020.

45. Md Whaiduzzaman, Md. Razon Hossain, Ahmedur Rahman Shovon, Shanto Roy, Aron Laszka, Rajkumar Buyya, and Alistair Barros, A Privacy-preserving Mobile and Fog Computing Framework to Trace and Prevent COVID-19 Community Transmission, IEEE Journal of Biomedical and Health Informatics (JBHI), Volume 24, Number 12, Pages: 3564-3575, ISSN: 2168-2194, IEEE Press, New Jersey, USA, December 2020.

Magazine Papers

46. Gagangeet Singh Aujla, Maninderpal Singh, Arnab Bose, Neeraj Kumar, Rajkumar Buyya, and Guangjie Hank, BlockSDN: Blockchain-as-a-Service for Software Defined Networking in Smart City Applications, IEEE Network Magazine, Volume 34, Issue 2, Pages: 12-20, ISSN: 0890-8044, IEEE Press, USA, March/April 2020.

Conference Papers

47. Shashikant Ilager, Rajeev Muralidhar, Kotagiri Rammohanrao, and Rajkumar Buyya, A Data-Driven Frequency Scaling Approach for Deadline-aware Energy Efficient Scheduling on Graphics Processing Units (GPUs), Proceedings of the 20th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2020, IEEE CS Press, USA), Melbourne, Australia, May 11-14, 2020. - **Best Paper Award**.

48. Qiheng Zhou, Minxian Xu, Sukhpal Singh Gill, Chengxi Gao, Wenhong Tian, Chengzhong Xu, and Rajkumar Buyya, Energy Efficient Algorithms based on VM Consolidation for Cloud Computing: Comparisons and Evaluations, Proceedings of the 20th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2020, IEEE CS Press, USA), Melbourne, Australia, May 11-14, 2020.

49. Shreya Ghosh, Jaydeep Das, Soumya K. Ghosh, and Rajkumar Buyya, CLAWER: Context-aware Cloud-Fog based Workflow Management Framework for Health Emergency Services, Workshop on Emerging Computing Paradigms and Context in Business Process Management, Proceedings of the 20th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2020, IEEE CS Press, USA), Melbourne, Australia, May 11-14, 2020.

50. Zhiheng Zhong, Jiabo He, Maria A. Rodriguez, Sarah Erfani, Ramamohanarao Kotagiri, and Rajkumar Buyya, Heterogeneous Task Co-location in Containerized Cloud Computing Environments, Proceedings of the 23rd IEEE International Symposium on Real-Time Distributed Computing (ISORC 2020, IEEE CS Press, USA), Nashville, Tennessee, USA, May 19-21, 2020.

51. Satish Kumar, Tao Chen, Rami Bahsoon, and Rajkumar Buyya, DATESSO: Self-Adapting Service Composition with Debt-Aware Two Levels Constraint Reasoning, Proceedings of the 15th ACM/IEEE International Symposium on Software Engineering for Adaptive and Self-Managing Systems (SEAMS 2020, IEEE CS Press, USA), Seoul, South Korea, May 25-26, 2020. - **Best Paper Award**.

52. Geeta C M, Tejashwinishivaram K S, Shreyas Raju R G, Raghavendra S, Rajkumar Buyya, Venugopal K R, S S Iyengar, and L M Patnaik, SRCBT: Secure Regeneration of Corrupted Blocks by TPA in Cloud, Proceedings of the 2020 Region 10 Symposium (TENSYMP, IEEE Press, New York, USA), Dhaka, Bangaladesh, June 5-7, 2020.

53. Roopa M.S., Pallavi B., Rajkumar Buyya, Venugopal K.R., S.S. Iyengar, and L.M. Patnaik, Social Interaction Enabled Industrial Internet of Things for Predictive Maintenance, Proceedings of the 5th International Conference on ICT for Sustainable Development (ICT4SD 2020, Springer, Germany), Panaji, Gao, India, July 23-24, 2020.

54. Lingxiao Xu, Minxian Xu, Jian Wang, Richard Semmes, Qi Wang, Hong Mu, Shuangquan Gui, He Yu, Wenhong Tian, and Rajkumar Buyya, A Data-driven Approach to Identify Resource Bottlenecks for Multiple Service Interactions in Cloud Computing Environments, Proceedings of the 16th EAI International Conference on Collaborative Computing:

Networking, Applications and Worksharing (CollaborateCom 2020), Shanghai, China, October 16-18, 2020.

55. Yamin Lei, Zhicheng Cai, Hang Wu, and Rajkumar Buyya, Cloud Resource Provisioning and Bottleneck Eliminating for Meshed Web Systems, Proceedings of the 13th IEEE International Conference on Cloud Computing (IEEE Cloud 2020, IEEE CS Press, USA), Beijing, China, October 19-23, 2020.

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

57. Hemant Mehta, Paul Harvey, Omer Rana, Rajkumar Buyya, and Blesson Varghese, WattsApp: Power-Aware Container Scheduling, Proceedings of the 13th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2020, IEEE CS Press, USA), Leicester, UK, Dec. 7-10, 2020.

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

5. Invited Presentations and Outreach

By the Lab Director:

Keynote Talks at International Conferences

1. New Frontiers in Cloud and Edge Computing, 2nd International Conference on Big Data Engineering and Technology (BDET2020), Singapore, Jan. 3-5, 2020.
2. New Frontiers in Cloud and Edge Computing, 12th International Conference on Computer and Automation Engineering (ICCAE 2020), Sydney, Australia, February 14-16, 2020.
3. New Frontiers in Cloud and Edge Computing, 2020 International Joint Conference on Information and Communication Engineering (JCICE 2020), Sydney, Australia, February 17-19, 2020.
4. New Frontiers in Cloud and Edge Computing, 5th International Conference on Cloud Computing and Big Data Analytics (ICCCBD 2020), Chengdu, China, April 10-13, 2020.
5. New Frontiers in Cloud and Edge Computing, 3rd International Conference on Advances in Computing Technologies (ICACT 2020), Bangalore, India, June 18-19, 2020.
6. New Frontiers in Cloud and Edge Computing, International Conference on Smart, Machine Intelligence, and Real-Time Computing (SmartCom 2020), Uttrakhand, India, June 26-27, 2020.
7. New Frontiers in Cloud and Edge Computing, International Conference on Modelling, Simulations and Optimizations (CoMSO-2020), Silchar, Assam, India, August 3-5, 2020.
8. New Frontiers in Cloud and Edge Computing, 3rd International Conference on Computational Intelligence and Data Engineering (ICCIDE-2020), Hyderabad, India, Aug 8-9, 2020.
9. New Frontiers in Cloud and Edge Computing, International Conference on Multidisciplinary Technologies and Challenges in Industry 4.0 (ICMTCI 2020), Bangalore, India, September 18-19, 2020.
10. New Frontiers in Cloud and Edge Computing, International Conference on Machine Learning, IoT and BigData (ICMIB-2020), Sarang, Odisha, India, 19th and 20th September, 2020.
11. Multi-Cloud Computing and Big Data Applications, International Conference on Computational Intelligence, Data Science and Cloud Computing (ICDC 2020), Kolkata, India, September 25-27, 2020.
12. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Cybersecurity in Emerging Digital Era (ICCEDE 2020), Noida, India, October 9-10, 2020.
13. Neoteric Frontiers in Cloud and Edge Computing, International Conference on Advances in IoT, High Performance and Edge Computing, Chennai, India, October 14-18, 2020.
14. Neoteric Frontiers in Cloud and Edge Computing, International Conference of Digital Transformation and Innovation (ICODTRIN 2020), Ecuador, Oct 28-29, 2020.
15. Neoteric Frontiers in Cloud and Edge Computing, Third International Conference on Applied Informatics (ICAI 2020), Covenant University, Nigeria, October 29-31, 2020.
16. Neoteric Frontiers in Cloud and Edge Computing¬4th IEEE International Conference on Distributed Computing, VLSI, Electrical Circuits and Robotics (IEEE DISCOVER 2020), Bantakal, Udupi, India, October 30-31, 2020.
17. Neoteric Frontiers in Cloud and Edge Computing¬9th International Conference on Software and Information Engineering (ICSIE 2020), Cario, Egypt, November 11-13, 2020.
18. Neoteric Frontiers in Cloud and Edge Computing¬3rd International Conference on Big Data and Machine Learning (BDML2020), Chengdu, China, November 13-15, 2020.
19. Neoteric Frontiers in Cloud and Edge Computing¬10th EAI International Conference on Cloud Computing (EAI CloudComp 2020), Qufu, China, December 11-12, 2020.

National Conferences

1. Cloud Computing using Aneka Platform, SPARC Workshop on Spatial Data Analysis in a Multi-Cloud/Fog Computing Environment, IIT Kharagpur, India, January 2, 2020.
2. FDP on Recent Advances in Computer Science and Allied Domains (RACSAD 2020), Sharda University, Noida, India, June 8-12, 2020.
3. Faculty Development Program (FDP) on Recent Advances in Computational Techniques, College of Engineering and Technology, Bhubaneswar, India, September 20, 2020.
4. Clouds for AI and AI for Clouds, Bangalore Technology Conclave 2020, Bangalore, India, November 3-4, 2020.

Seminars - in Cloud Computing area:

1. New Frontiers in Cloud and Edge Computing, GLA University, Mathura, India, April 23, 2020.
2. New Frontiers in Cloud and Edge Computing, Sagar Institute of Research, Technology (SIRT), Bhopal and Defence Institute of Advanced Technology (DIAT), Pune, India, June 2, 2020.
3. New Frontiers in Cloud and Edge Computing, Indian Institute of Information Technology (IIIT) Kottayam, India, July 6, 2020.
4. New Frontiers in Cloud and Edge Computing, The University of Canberra, Australia, September 14, 2020.

6. Selected Community Services

By the Lab Director:

IEEE Computer Society

1. Advisory Board, IEEE Technical Committee on Scalable Computing

Software: Practice and Experience (Wiley)

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

Journal Editorials
1. Editorial Board Member, *International Journal of Parallel, Emergent and Distributed Systems (IJPEDS)*, ISSN: 1744-5760, Taylor & Francis Group, UK, 2006-2013. IJPEDS), ISSN: 1744-5760, Taylor & Francis Group, UK, 2013-to date.
2. Co-Editor-in-Chief, Journal of Cloud Computing: Advances, Systems and Applications (JoCCASA), ISSN: 2192-113X, Springer, UK, 2012-to date.
3. Associate Editor-in-Chief, The ITU Journal: ICT Discoveries, International Telecommunication Union (ITU), United Nations, Geneva, Switzerland, 2017-2020.

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 Chair 20th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGrid 2020), May 11-14, 2020, Melbourne, Australia.
2. Track Chair, 29th IEEE International Conference on Computer Communications and Networks (ICCCN 2020), August 3 - August 6, 2020, Honolulu, Hawaii, USA.
3. 40th IEEE International Conference on Distributed Computing Systems (ICDCS 2020), July 8-10, 2020, Singapore.
4. The IEEE/ACM International Conference for High Performance Computing, Networking, Storage, and Analysis (SC 2020), November 15-20, 2020, Atlanta, USA.
5. SuperComputing Asia (SCA 2020), Feb. 24-27, 2020, Singapore.
6. First Conference on Urban Data Science (UDS 2020), January 20-21, 2020, Chennai, India.

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 have received the Doctor of Philosophy (PhD)-Engineering degree from the School of Computing and Information Systems, the University of Melbourne in 2020. In my PhD thesis titled "Quality of Service (QoS)-aware Application Management in Fog Computing Environments", I have investigated how the service quality of Internet of Things (IoT) software applications can be enhanced by placing them efficiently over highly distributed Edge/Fog computing nodes. This thesis is a very timely contribution to the state-of-the-art as it supports the creation of modular IoT applications for smart city and digital healthcare.

I have joined *Cloud Computing and Distributed Systems (CLOUDS) Laboratory, Department of Computing and Information Systems, University of Melbourne, Australia* in February 2016. I have been awarded with Melbourne International Research Scholarship (MIRS) and Melbourne International Fee Remission Scholarship (MIFRS) for supporting my studies.

I have a strong research background in Cloud computing, IoT software, Fog/Edge computing, and Distributed systems which is evidenced by my 20+ publications in high-quality journals, conferences, and book series. Most of my publications are listed Q1 in SJR ranking and they have already attracted 1300+ Google Scholar citations that help me to attain h-index 12 within a very short period. I have also contributed to FogBus and iFogSim software systems which are being used by many research organizations and academic institutions.

I moved to RMIT University in late 2020 as a Research Fellow in the School of Computing Technologies.

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: Shashikant Ilager

- I joined CLOUDS Lab as a PhD student in March 2017.
- 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.
- I have recently submitted my PhD thesis on "Machine Learning-based Energy and Thermal Efficient Resource Management Algorithms for Cloud Data Centres".

Here are my papers published in 2020:

- 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 [Best paper award].
- Shashikant Ilager, Rajeev Muralidhar, and Rajkumar Buyya, Artificial Intelligence (AI)-Centric Management of Resources in Modern Distributed Computing Systems, In Proceedings of the IEEE Cloud Summit, Harrisbury, Pennsylvania, USA, October 21-22, 2020.
- Shreshth Tuli, Shashikant Ilager, Kotagiri Ramamohanarao, and Rajkumar Buyya, Dynamic Scheduling for Stochastic Edge-Cloud Computing Environments using A3C Learning and Residual Recurrent Neural Networks, IEEE Transactions on Mobile Computing. ISSN: 1536-1233, IEEE Computer Society Press, USA (in press, accepted on Aug 13, 2020).
- Shashikant Ilager, Kotagiri Ramamohanarao, and Rajkumar Buyya, Thermal Prediction for Efficient Energy Management of Clouds using Machine Learning, IEEE Transactions on Parallel and Distributed Systems (TPDS), Volume 32, No. 5, Pages: 1044-1056, ISSN: 1045-9219, IEEE CS Press, USA, May 2021.

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 joined CLOUDS lab in 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 "Cost-efficient 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 2020, 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 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
- **T. Islam**, H. Wu, S. Karunasekera, and R. Buyya, "SLA-based Scheduling of Spark Jobs in Hybrid Cloud Computing Environments", *IEEE Transactions on Computers (TC)* [Under Minor Review].
- **M. T. Islam**, S. Karunasekera, and R. Buyya, "Performance and Cost-efficient Spark Job Scheduling based on Deep Reinforcement Learning in Cloud Computing Environments." IEEE Transactions on Parallel and Distributed Systems (TPDS) [Under review]

Currently, I am working on the following projects:

- SDN-enabled Intent-based resiliency in tactical battlefield networks. (In collaboration with Dr. Adel Nadjaran Toosi from Monash University)
- RAPID: Real time data analytics platform for interactive data mining. (DST project in collaboration with Prof. Shanika Karunasekera).

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

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

Member Self Profile: 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.

Zhiheng Zhong and Rajkumar Buyya, A Cost-efficient Container Orchestration Strategy in Kubernetes-based Cloud Computing Infrastructures with Heterogeneous Resources, ACM Transactions on Internet Technology (TOIT), Volume 20, No. 2, Article 15, Pages: 1-24, ISSN: 1533-5399, ACM Press, New York, USA, April 2020.

Zhiheng Zhong, Jiabo He, Maria A. Rodriguez, Sarah Erfani, Ramamohanarao Kotagiri, and Rajkumar Buyya, Heterogeneous Task Co-location in Containerized Cloud Computing Environments, Proceedings of the 23rd IEEE International Symposium on Real-Time Distributed Computing (ISORC 2020, IEEE CS Press, USA), Nashville, Tennessee, USA, May 19-21, 2020.

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.

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. 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. I have published two research articles: "A fog-driven dynamic resource allocation technique in ultra-dense femtocell networks" in the "Journal of network and Computer Applications", and "An Application Placement Technique for Concurrent IoT Applications in Edge and Fog Computing Environments" in "IEEE Transactions on Mobile Computing". Currently in the third year of my PhD career, I am working on adoption of Deep Reinforcement Learning techniques in Fog/Edge computing Environments. I submitted a research article "A Distributed Deep Reinforcement Learning Technique for Application Placement in Fog and Edge Computing Environments" in "IEEE Transactions on Mobile Computing". Besides, I am actively working on development of second version of FogBus framework, called FogBus2, which offers dynamic scheduling, scalability, profiling, and resource discovery in fog/edge computing environments.

My research interests include IoT, Cloud/Fog/Edge Computing, Distributed Systems, Machine Learning, and Deep Reinforcement Learning.

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. Muhammad Hilman, Maria Rodriguez, and Rajkumar Buyya, Multiple Workflows Scheduling in Multi-tenant Distributed Systems: A Taxonomy and Future Directions, ACM Computing Surveys, Volume 53, No. 1, Article No. 10, Pages: 1-39, ISSN: 0360-0300, ACM Press, New York, USA, May 2020.

I now joined back to 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, I specially focus on challenges related to scheduling microservices-based IoT applications within Fog environments. Explored areas include QoS-aware scheduling, mobility-aware scheduling and reliability-aware scheduling of applications.

For more information please refer,

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

Member Self Profile: Amanda Jayanetti

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

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

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

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: Anupama Mampage

I joined CLOUDS Lab as a PhD student in February 2020 under the supervision of Prof. Rajkumar Buyya and Prof. Shanika Karunasekera. I completed by BSc Engineering (Hons) degree, specialized in Electronic and Telecommunication Engineering from the University of Moratuwa, Sri Lanka in 2017 and worked in the Software Industry as part of a Research and Development team at a large Telecommunication Provider in the country, prior to joining the lab.

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

The first paper of my PhD research titled, "Deadline-aware Dynamic Resource Management in Serverless Computing Environments", is to be published in the proceedings of the CCGrid2021 conference.
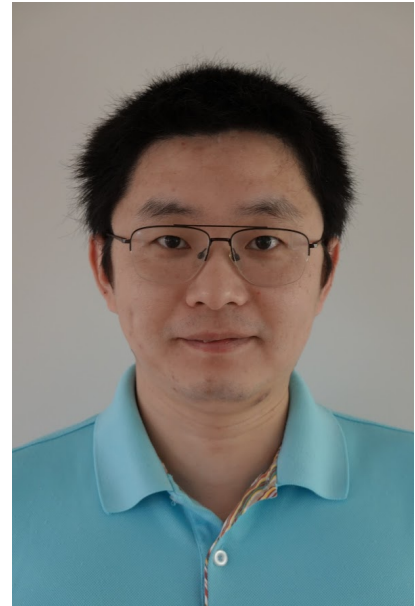
LinkedIn: www.linkedin.com/in/anupama-mampage

Member Self Profile: Jie Zhao

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

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

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

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

Publications:

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

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

Member Self Profile: Rajeev Muralidhar

I joined the CLOUDS Laboratory in Sep. 2019 as a part time PhD student. I work full time at Amazon Web Services as 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.

Here are some of my works in 2020:

- Shashikant Ilager, Rajeev Muralidhar, Kotagiri Rammohanrao, and Rajkumar Buyya, A Data-Driven Frequency Scaling Approach for Deadline-aware Energy Efficient Scheduling on Graphics Processing Units (GPUs), Proceedings of the 20th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2020, IEEE CS Press, USA), Melbourne, Australia, May 11-14, 2020.
- Rajeev Muralidhar, Renata Borovica-Gajic, and Rajkumar Buyya, Energy Efficient Computing Systems: Architectures, Abstractions and Modeling to Techniques and Standards, ACM Computing Survey
- Shashikant Ilager, Rajeev Muralidhar, and Rajkumar Buyya, Artificial Intelligence (AI)-Centric Management of Resources in Modern Distributed Computing Systems, Proceedings of the IEEE Cloud Summit 2020 (IEEE CS Press, USA), Harrisburg, PA, USA, October 21-22, 2020.

Member Self Profile: Ming Chen

I joined CLOUDS lab as a PhD student at Dec. 2020 under the primary supervision of Prof. Rajkumar Buyya and second supervision of Dr. Maria Alejandra Rodriguez.

Before my PhD journey, I obtained my Bachelor's degree in Engineering from Hunan University in 2016, after which I worked as a research engineer and project manager at Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences. My previous working fields include speech recognition, FinTech, Cloud Robotics, etc.

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

Selected publications:

- Ming Chen*, Yanying Lin*, Kejiang Ye, Lujia Wang, Cheng-zhong XU. "PathTracing: Fault Tracing and Prediction for Telecom Core Networks". The 41st IEEE International Conference on Distributed Computing Systems (ICDCS 2021, Under review)
- Peng Lin, Kejiang Ye, Ming Chen, Cheng-Zhong Xu. "DCSA: Using Density-Based Clustering and Sequential Association Analysis to Predict Alarms in Telecommunication Networks". The 25th IEEE International Conference on Parallel and Distributed Systems (ICPADS 2019), Tianjin, China.
- Yuhang Zhang, Wensi Yang, Wanlin Sun, Kejjiang Ye, Ming Chen, Chengzhong Xu. "The Constrained GAN with Hybrid Encoding in Predicting Financial Behavior". AIMS 2019 (2019 International Conference on AI and Mobile Services), San Diego, USA. Jun. 2019   [Best Paper Award]
- Wanlin Sun, Ming Chen*, Cheng-zhong Xu, et al. "Semi-Supervised Anti-Fraud Models for Cash Pre-Loan in Internet Consumer Finance." IEEE ICPS 2019 (IEEE International Conference on Industrial Cyber Physical Systems), Taipei, Taiwan, May 2019 ;
- Ming Chen, Lujia Wang, Cheng-zhong Xu,   Renfa Li. "A Novel Approach of System Design for Dialect Speech Interaction with NAO robot." IEEE 18th ICAR(International Conference on Advanced Robotics）, Hong Kong , Aug 2017

Self-Profile: Qifan Deng

I obtained a bachelor of science at Beijing Institute of Technology, as well as a bachelor of management.
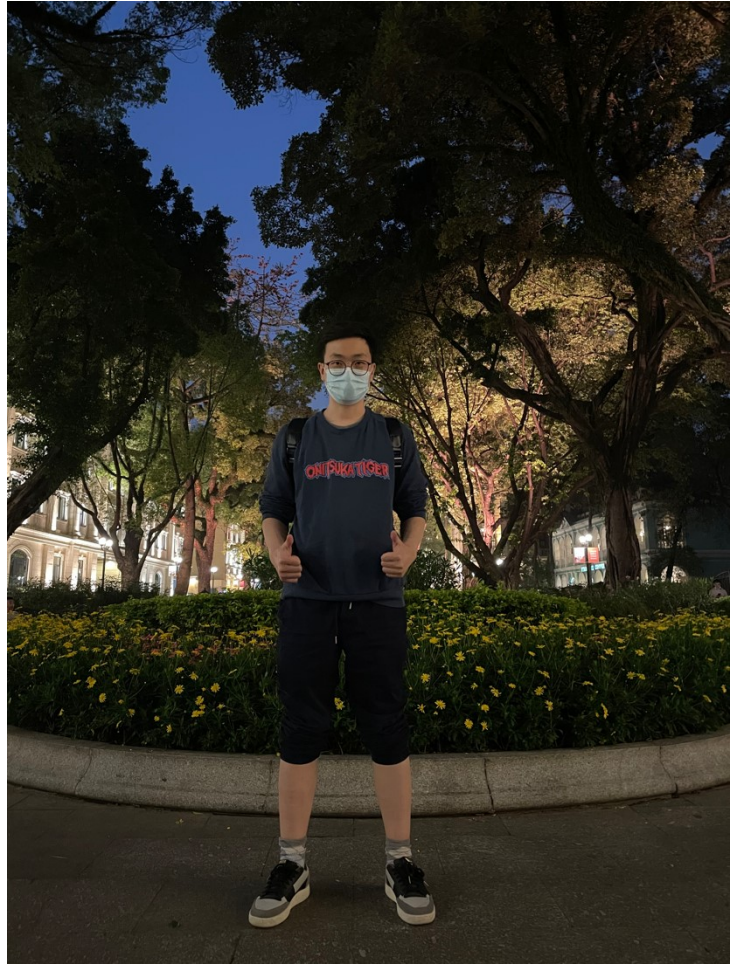
I joined the CLOUDS Laboratory in November 2019, as a master majoring in computer science at University of Melbourne.

I am doing research under the supervision of Rajkumar Buyya, working on a scalable distributed framework for scheduling and processing Internet of Things requests.

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

Home Page: https://qifan.dev
GitHub: https://github.com/pancak3

Member self-profile: Siddharth Agarwal

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

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

Currently, as part of my Master of Science degree research component, I'm investigating and exploring the concepts of Serverless Computing and exploiting the AI/ML techniques to optimise the Cold Start challenges in the Function as a Service offerings of Cloud Computing. I have submitted a research work "A Reinforcement Learning Approach to Reduce Serverless Function Cold Start Frequency", accepted at the workshop on Serverless To Serve more at Scale (STEERS '21/CCGrid 2021). I am working towards the completion of my MSc. thesis and will be finishing my coursework by June 2021.

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

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 2020, I and coauthors have got the following papers published/written:

- Yamin Lei, Zhicheng Cai, Hang Wu, and Rajkumar Buyya, Cloud Resource Provisioning and Bottleneck Eliminating for Meshed Web Systems, Proceedings of the 13th IEEE International Conference on Cloud Computing (IEEE Cloud 2020, IEEE CS Press, USA), Beijing, China, October 19-23, 2020.

- Zhicheng Cai, Duan Liu, Yifei Lu, and Rajkumar Buyya, Unequal-Interval based Loosely Coupled Control Method for Auto-scaling Heterogeneous Cloud Resources for Web Applications, Concurrency and Computation: Practice and Experience (CCPE), Volume 32, No. 23, Pages: 1-16, ISSN: 1532-0626, Wiley Press, New York, USA, December 2020.

- Zhicheng Cai and Rajkumar Buyya, Inverse Queuing Model based Feedback Control for Elastic Container Provisioning of Web Systems in Kubernetes, IEEE Transactions on Computers (TC), ISSN: 0018-9340, IEEE CS Press, Los Alamitos, CA, USA (in press, accepted on Jan. 4, 2021).

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've returned to the Beijing University of Posts and Telecommunications (BUPT, China) in Sep. 2020 and continued 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.

My recent work is listed as below:
1) Linna Ruan, Shaoyong Guo, Xuesong Qiu and Rajkumar Buyya "Chapter 2: Fog Computing for Smart Grids: Challenges and Solutions", Electric Vehicle Integration in Smart Micro grid Environment, CRC press, 2020. (preprint)

The full list of my publications can be found at:
https://www.researchgate.net/profile/Ruan-Linna

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 mentor, he often gives us some meaningful research guidance at the weekly group meeting, and I also obtains a lot of valuable advices.

My 2020 work led to publication of a paper:

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

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 work:

- Dongcheng Zhao, Gang Sun, Long Luo, Hongfang Yu, Victor Chang, and Rajkumar Buyya, Security-SLA-Guaranteed Service Function Chain Deployment in Cloud-Fog Computing Networks, Journal of Cluster Computing, ISSN: 1386-7857, Springer, Netherlands (in press, accepted on March. 25, 2021).

8. Selected Projects/Programs

Cloudbus: A Toolkit for Market-Oriented Cloud Computing

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

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

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

The Cloudbus project

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

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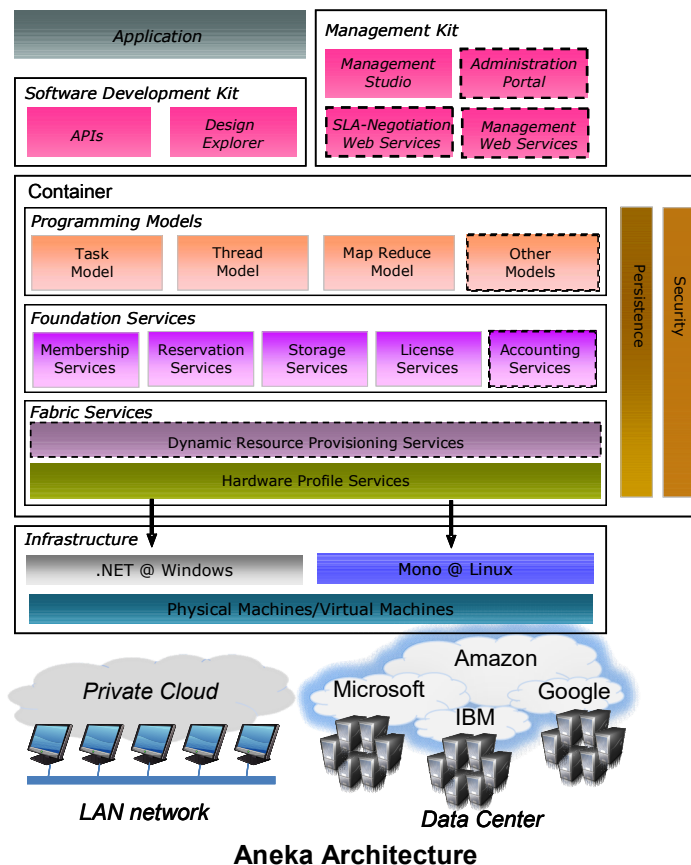
Future Research is Driven By:

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

Aneka: .NET-based Cloud Computing

Web: http://www.manjrasoft.com

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

- A configurable and flexible execution platform (container) enabling -

    - Pluggable services;
    - Security implementations - multiple authentication / authorization mechanisms such as role-based security and Windows domain-based authentication;
    - Multiple persistence options including RDBMS, SQL Express, MySQL and flat files;

- SDK (Software Development Kit) supporting multiple programming models including –

    - Object-oriented Thread model,
    - Task model for legacy applications
    - Map Reduce model for data-intensive applications
    - Custom tools such as Design Explorer for parameter sweep studies

- Easy to use management tool for SLA and QoS negotiation and resource allocation.

- Cloudbrusting of application tasks across multiple Clouds (e.g., Azure and AWS)

- In 2020, we released Aneka 5.0 edition.

Aneka Architecture

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QoS-Oriented Cloud Workflow Engine

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

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

We extend the Cloudbus WMS as a PaaS (Platform-as-a-Service) to support the cloud-computing paradigm. Specifically, the project aims to:
- Define an architectural framework and principles for the development of QoS-based workflow management in cloud environments,
- Develop QoS-based algorithms for scheduling scientific workflow applications,
- Develop policies and resource management algorithms tailored for the cloud resource model,
- Implement a prototype system by incorporating the algorithms and policies developed above, and
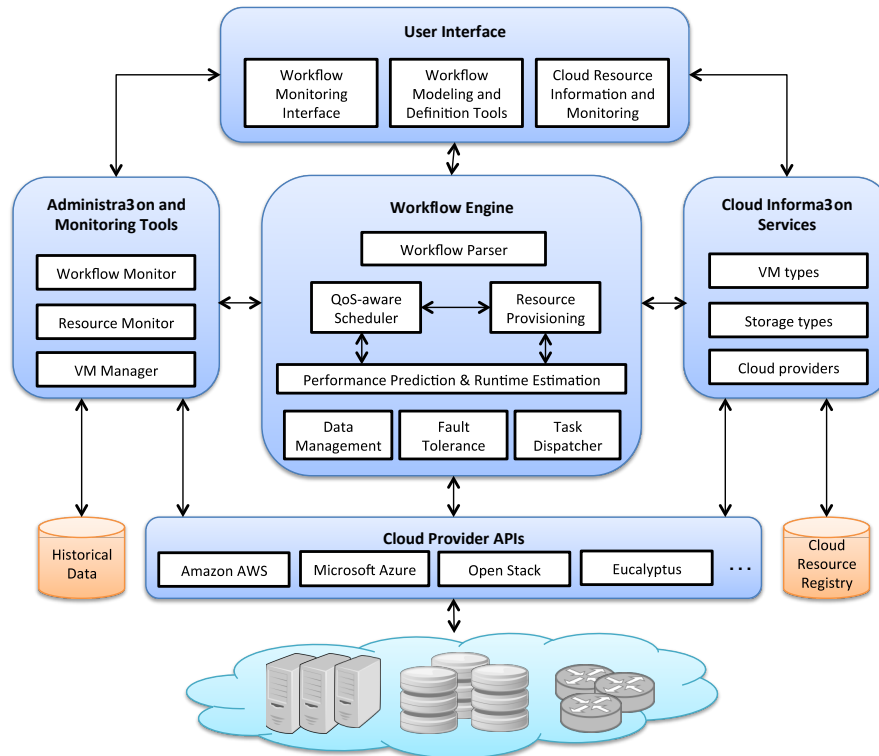- Develop real world demonstrators in various scientific domains such as astronomy.

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

Some References:

- Muhammad Hilman, Maria Rodriguez, and Rajkumar Buyya, Multiple Workflows Scheduling in Multi-tenant Distributed Systems: A Taxonomy and Future Directions, ACM Computing Surveys, Volume 53, No. 1, Article No. 10, Pages: 1-39, ISSN: 0360-0300, ACM Press, New York, USA, May 2020.
- Maria A. Rodriguez, Ramamohanarao Kotagiri, and Rajkumar Buyya, Detecting Performance Anomalies in Scientific Workflows using Hierarchical Temporal Memory, Future Generation Computer Systems, Volume 88, Pages: 624-635, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, November 2018.
- Maria A. Rodriguez and Rajkumar Buyya, Scheduling Dynamic Workloads in Multi-tenant Scientific Workflow as a Service Platforms, Future Generation Computer Systems, Volume 79, No. 2, Pages: 739-750, ISSN: 0167-739X, Elsevier Press, Amsterdam, The Netherlands, February 2018.
- Maria A. Rodriguez and Rajkumar Buyya, 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.
- Amanda Jayanetti and Rajkumar Buyya, J-OPT: A Joint Host and Network Optimization Algorithm for Energy-Efficient Workflow Scheduling in Cloud Data Centers, Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2019, IEEE CS Press, USA), Auckland, New Zealand, Dec. 2-5, 2019.
- Shashikant Ilager, Rajeev Muralidhar, Kotagiri Rammohanrao, and Rajkumar Buyya, A Data-Driven Frequency Scaling Approach for Deadline-aware Energy Efficient Scheduling on Graphics Processing Units (GPUs), Proceedings of the 20th IEEE/ACM International Symposium on Cluster, Cloud, and Internet Computing (CCGrid 2020, IEEE CS Press, USA), Melbourne, Australia, May 11-14, 2020.

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

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

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

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

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

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

- In 2020, we released CloudSim 5.0

Some References:

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

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

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

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

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

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

Some References:

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

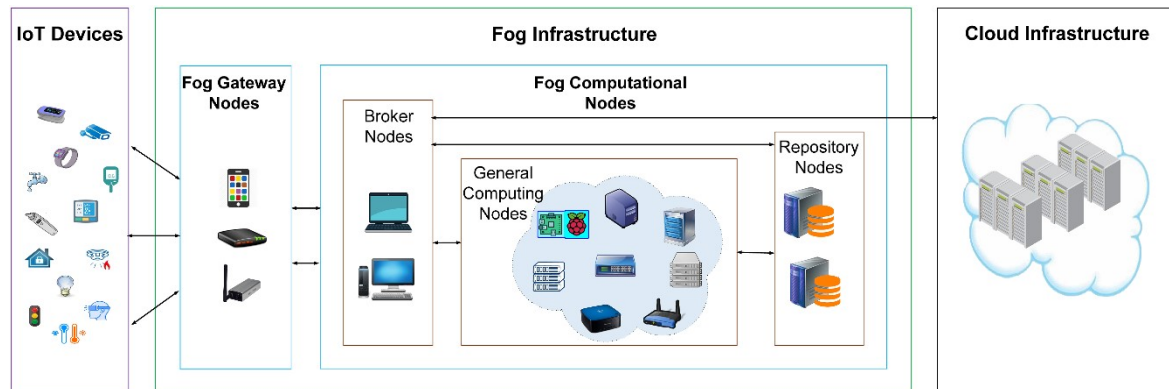# FogBus: A Blockchain-based Lightweight Framework for Edge and Fog Computing

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] Wendy Yanez, Redowan Mahmud, Rami Bahsoon, Yuqun Zhang, and Rajkumar Buyya, Data Allocation Mechanism for Internet-of-Things Systems With Blockchain, IEEE Internet of Things Journal, Volume 7, Number 4, Pages: 3509-3522, ISSN: 2327-4662, IEEE Computer Society Press, USA, April 2020.
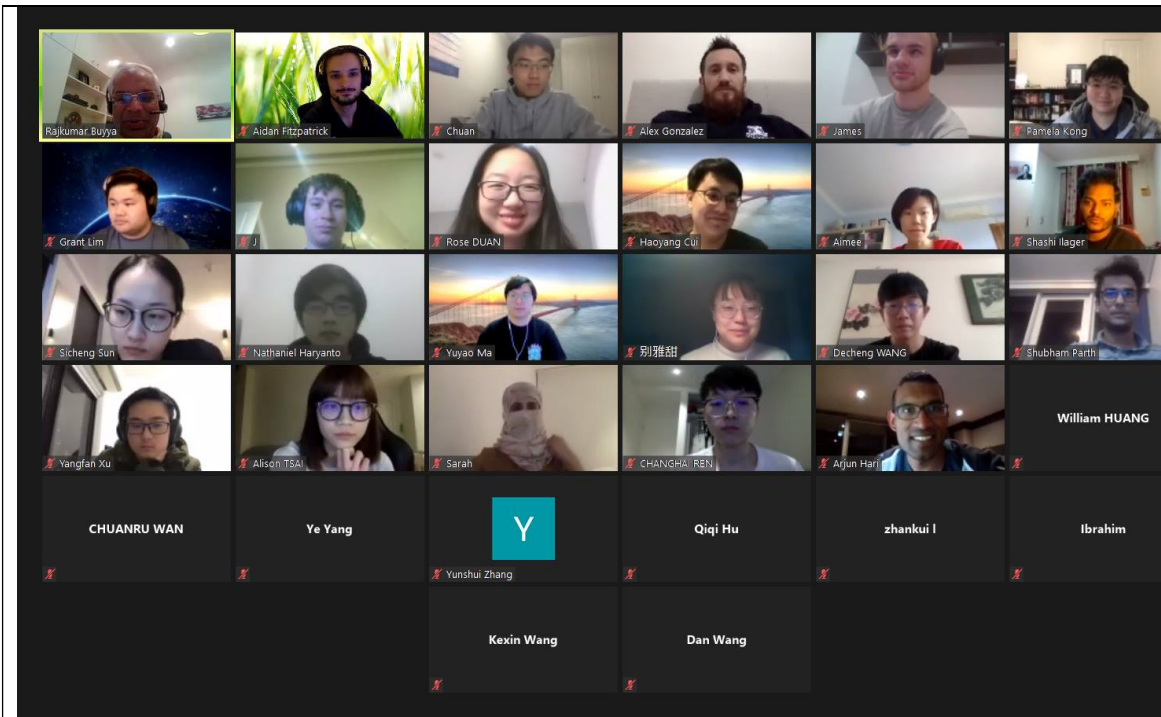
9. Moments with Visitors, Colleagues and International Hosts

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

12th International Conference on Computer and Automation Engineering (ICCAE, Sydney, Australia, February 14-16, 2020. Hosted at Macquarie University.

A Zoom session snap with some of the students of Semester 1, 2020 subject COMP90015: Distributed Systems

International Conference on Modelling Simulation and Optimization (CoMSO-2020), August 3-5, 2020