Journal Name

Original Research Paper

Application of graph theory concepts in computer networks and its suitability for the resource provisioning issues in Cloud Computing

R.Kanniga Devi[1], G.Murugaboopathi[2]

[1] *Assistant Professor, Department of Computer Science and Engineering, Kalasalingam University, Krishnankoil, Tamilnadu, India;*
[2] *Associate Professor, Department of Computer Science and Engineering, Kalasalingam University, Krishnankoil, Tamilnadu, India.*

Article history
Received:
Revised:
Accepted:

*Corresponding Author:
R.Kanniga Devi,
Kalasalingam University,
Krishnankoil, Tamilnadu,
India;
Email:
rkannigadevi@gmail.com

Abstract: Cloud computing, a kind of web service provisioning model, provides immense benefits over traditional IT service environments with the help of virtualization technology. As cloud computing is not a fully matured paradigm, it poses many open issues to be addressed. The key research problem in cloud computing is efficient resource provisioning which is due to its complex and distributed architecture. Graph-based representations of complex networks provide simpler views and graph theoretical techniques provide simpler solutions for lot of issues inherent in networks. Hence, this paper begins with exploration of graph theory applications in computer networks with specific focus on graph theory applications in cloud computing. This work pays attention to basic resource provisioning problems arise in cloud computing environments and presents some conceptual graph theoretical suggestions to address these issues.

Keywords: Computer Network**;** Cloud Computing; Graph theory; Resource provisioning

Introduction

The next step in the evolution of distributed computing is cloud computing. It inherits existing distributed computing models such as grid computing, utility computing and adds additional flavour namely virtualization. Large-scale processing and storage of data are very much simplified with the advent of cost-effective cloud computing solutions. The Cloud Data Center (CDC) [1] is very complex with resources distributed globally leading to several issues. The authors of [2-6] addressed several key and fundamental cloud computing issues like resource provisioning, security, privacy, energy and interoperability, but this list is not limited. From the perspective of cloud service provider and cloud service consumer, these issues provide different pictures. While cloud computing provides opportunities to migrate the IT business services online, these key issues need to be resolved before it is accepted as a successful business model.

This article identifies the opportunities of graph theory [7] based solutions for the resource provisioning issues inherent in cloud computing. First, it starts with graph theory applications in various areas in computer networks and then explores its suitability to address the resource provisioning issues of cloud. Graph theory is part of discrete mathematics and useful structure to model relationship between objects. Graph theory mainly finds its applications in network modeling, biology, electrical network, computational algorithms and scheduling. Graph theoretical techniques are highly used by computer science applications especially in modeling and routing in networks. Representing a problem as a graph can provide a different point of view and makes a problem much simpler. It provides tools for solving the problem and set of techniques for analysing graphs.

This work has two main parts. The first part gives an

Science Publications

DOI:

overview of graph theory applications in computer networks. As cloud data center has a set of interconnected systems, graph theoretical solutions on computer networks can well be applied on cloud with suitable modifications to address its issues. The second part gives an overview of graph theory applications in cloud. The main idea behind this work is to find out the scope for applicability of graph theory to address resource provisioning issues in cloud.

Key research issues in Cloud Computing

Resource Provisioning

The authors of [8-12] proposed that unlike traditional resource provisioning where resources are provisioned as it is, cloud demands efficient resource provisioning algorithms to provision virtualized resources to meet SLA requirements. Virtualized data centers are envisioned to provide better management flexibility, lower cost, scalability, better resources utilization, and energy efficiency, but virtualization is not an easy task to do.

Security

The authors of [13-17] discussed that as users and corporate information reside on third-party systems, no one can guarantee how secure the data are. It is prone to leakage of information and attack. Security is a primary issue which should be handled by all the cloud service providers to retain their business in the market. They should take steps to protect data and its privacy. Five most representative security and privacy attributes are confidentiality, integrity, availability, accountability, and privacy-preservability.

Cost

The authors of [18-21] proposed that the public cloud offers pay per use, which can provide low-cost options for short-term projects. Still, for long-term use, enterprise IT organizations may be better off making a capital investment to purchase additional hardware and software. Enterprises need to conduct a break-even analysis to determine whether a public or private cloud would be more cost-effective for them. From the perspective of provider, they are interested in customer satisfaction and generating revenue out of their services. From the perspective of consumer, they are interested in cost-effective solutions. To balance these two points, cost-effective cloud solutions need to be developed.

Reliability

The authors of [22-25] stated that due to high system complexity and distributed structure, even carefully engineered data centers are subject to a large number of failures. Fault tolerant systems should be built to address reliability concerns. Because of the abstraction nature of cloud environment, there arise a need to develop new or extend traditional fault tolerant approaches. VM migration and Server consolidation are the major threatening factor for fault tolerance as they incur service downtime.

Interoperability

The authors of [26-27] stated that interoperability of heterogeneous cloud platforms are difficult because they use distinct hypervisor and VM technologies. The platforms also use various security standards and management interfaces. Multiple vendors with different product standards poses challenges for interoperability. Cloud adoption will be stopped if there is not a good way of integrating data and applications across clouds; hence a unified cloud interface and open standards need to be developed.

Energy

The authors of [28-32] stated that increasing demand for computational power, leads to setting up large-scale data centers. On the other side, the power consumption of these large-scale data centers is enormous. Hence, design of energy efficient hardware and intelligent resource management techniques is required. Due to enormous power consumption, carbon dioxide (CO_2) emission is also more contributing to the greenhouse effect. Hence number of practices need to be applied to achieve energy efficiency, such as improvement of applications' algorithms, energy efficient hardware and energy-efficient resource management strategies on a virtualized data center.

Out of all these above mentioned key issues, this work pays much attention to resource provisioning issue and application of graph theory on it.

Resource Provisioning in Cloud

In cloud computing, resource provisioning [8-12] is the allocation of a cloud data center resources to a user. When cloud data center accepts requests for hardware or software resources, it must create and provision them as virtualized resources. It means the monitoring, dynamic selection/scheduling, deployment/placement and management/load balancing of software and hardware resources for ensuring Service Level Agreement (SLA). The SLA is an agreement between the cloud service provider and the user on guaranteeing Quality of Service (QoS). The provisioning can be done in several different ways. In particular, this work addresses the following aspects of resource provisioning from CDC:

- Efficient monitoring for provisioning CDC resources.
- Optimal VM placement and migration in CDC for energy-efficient resource provisioning.
- Proper locating of CDCs and allocation of CDCs to the source of requests.
- Clustering distributed CDCs for faster server provisioning.
- Uniform assignment of clients to CDC servers.
- Traffic-aware VM migration to load balance cloud servers.

Efficient monitoring for provisioning CDC resources

Task scheduling, load balancing are complicated in cloud computing environment due to its abstract heterogeneous architecture, dynamic behaviour and resource heterogeneity. Monitoring of resources is required before performing scheduling and load balancing.

Optimal VM placement and migration in CDC for energy-efficient resource provisioning

Keeping lot of PMs and VMs running in the datacenter consumes more energy, leading to higher operating costs. Hence identifying physical machines with least load and migrating its load to some other physical machines and then shutting them down saves energy. Conservation of energy may be better achieved through optimal placement of VMs on the PMs and performing VM migrations, so that energy consumption may be maintained at desirable level.

Proper locating of CDCs and allocation of CDCs to the source of requests

The requests for the CDC services can come from different parts of the world. The term source of requests/clients denote the users who make requests to various cloud data center services. The distance between the cloud data center and the source of requests is a major factor influencing the quality of service in terms of response time and latency. Cloud data center allocation is one of the major issues in cloud computing. An efficient allocation of cloud data center to the source of requests may improve the quality of services.

Clustering distributed CDCs for faster server provisioning

Normally cloud data centers are distributed across the world to increase the availability of services by remote mirroring, replication which are the kind of redundancy mechanisms. It is distributed mainly for disaster recovery. Clustering region-wise deployed cloud data centers will provide rapid responses.

Uniform assignment of clients to CDC servers

In a distributed cloud data center environment, load balancing techniques direct the requests to the closest source or to the source with the most able capacity to serve the request. Variety of algorithms are used to perform load balancing. But there is a trade-off always exits between choosing the closest cloud data center and balancing the load of cloud data center. Sometimes a cloud data center closer to the user location may be in overloaded condition, during this case, the requests will be routed to a distant cloud data center which is capable of handling the requests. Hence, there arise a need to deal with this trade-off which may consider both proximity and load at the same time.

Traffic-aware VM migration to load balance cloud servers

Upon receiving the load information, cloud broker must invoke load balancing procedure to distribute the load uniform across the hosts in the CDC . It can be done by migrating some of the VMs from overloaded hosts to underloaded hosts considering only server-side constraints. Network-side constraints also need to be considered to enhance the performance of CDCs.

Graph theory applications in computer networks

This section summary of some of the works, which applied graph theory in various types of computer network.

Author	**Graph theory technique**	**Issue addressed**	**Type of network**
[33-35]	Graph coloring	Interference reduction, Interference Aware TDMA Link scheduling, Job Scheduling/Assignment problems, Resource allocation	Wireless networks-Mobile Adhoc Networks and Sensor networks
[36-42]	Dominating set and Connected Dominating Set	Routing, fault tolerance, energy-efficiency, delivery delay reduction, connectedness, Virtual backbone construction for efficient routing, Overlay network construction, Search space reduction, Clustering nodes	
[43]	Random Graphs	Connectivity ,Scalability, Routing, Congestion handling, Modeling the network	
[45]	Shortest path algorithms	Route computation for communication	
[46]	Spanner	Minimum power assignment	
[55]	Topological graph	Network Coverage problem	
[56]	Graph embedding	Routing	
[65]	Graph labeling	Fast communication via radio labeling	

[53]	Gabriel graph, Unit graph	Routing with guaranteed delivery	
[63]	Network flow	Flow optimization	Mesh network
[61]	Tree	Data center/ network modeling	Datacenter
[62]	Graph matching	Abnormal event detection in network by graph comparison	General network
[44]	Spanning and Minimum Spanning tree algorithms	Loop-free Connectedness, Clustering	
[64]	Graph traversal	Searching an object	General network query optimization
[57-58]	Graph partitioning	Clustering, faster communication	Real road networks, World Wide Web
[47,67]	Virtualized graph model	Grid service reliability evaluation	
[48]	Set Covering Problem	Mapping applications with data sets	Grid
[49]	Cayley digraphs	Design of scalable Interconnection networks	
[50]	KD-Tree	Multi-dimensional Search	Database
[51]	detaticapaC tes gnitanimod	Minimum capacitated dominating set construction	Wireless networks
[52]	noitacol ytilicaF melborp	Locating centers	General facility

Table.1 Graph theory in computer networks

Table.1 lists some of the possible graph theory applications in various types of network. Since cloud is a kind of network, these traditional graph theoretical techniques can be analyzed for their suitability to address resource provisioning issues in cloud and section 6 presents some conceptual suggestions for it.

Graph theory applications in cloud computing

This section provides summary of works, which applied graph theory in cloud.

DOI:

Author	**Graph theory technique**	**Issue addressed**	**Limitation**
[66]	Hypergraph	Modeling cloud network	Scheduling is done in two-phases which increases makespan. If done in single phase, it may minimize the makespan of the workflow. This work didn't consider dynamic workflows whose execution pattern changes over time as well.
[67]	Spanning tree	Cloud service reliability	Cloud service reliability model and evaluation algorithm have not been validated by simulation and real-life data. They have proposed only theoretical model.
[68]	Graph partitioning	Software deployment in mobile cloud	This work considered only minimizing the bandwidth between software components. It didn't minimize the execution time of tasks. This work provide scope for integrating

DOI:

			their algorithms to address energy consumption objective.
[69]	Flow network algorithms-Ford-Fulkerson	Optimizing MapReduce performance in cloud	Validation of min-cost flow model for data and VM placement is to be done in larger real VM clusters.
[70]	Topological graph theory	Topology management in cloud	Enterprise Topology Graph (ETG) is to be built as reusable building blocks to address specific problem domains with broad set of basic operations.
[71]	Graph mapping	Congestion minimization in cloud network	Only mapping of two classes of workloads, namely depth-d trees and complete graph are considered.
[72]	Predicate-based graph	Modeling and Testing cloud	This model supports only stateless atomic operations expressed in context free grammar. Some other attributes such as scalability, exception handling, dynamic binding, service interactions can also be

			considered to make the model valuable.
[73]	Graph cut theory	Virtual Machine (VM) clustering in cloud	Time taken for VM clustering is a valuable parameter, which is not mentioned.
[74]	Graph model	Security model for VM hypervisor in cloud	Not mentioned the applicability of hypervisor security model on the specific type of hypervisor architectures, namely hosted or bare-metal.

Table.2 Graph theory in cloud

From table 2, it is observed that only a very minimal literature is available on graph theory applications in cloud and most of these works overlooked its application on resource provisioning. Thus, it opens lot of opportunities to apply graph theoretical techniques to address resource provisioning issues in cloud.

Some conceptual suggestions for the suitability of graph theory techniques for addressing resource provisioning in cloud

This section considers some of the graph theoretical techniques from table 1 and suggests the following aspects of resource provisioning in cloud and the suitability of such graph theoretical models and techniques to address its issues.

How to perform efficient monitoring for provisioning CDC resources?

Monitoring the complex, distributed cloud architecture for tracking resource status is a challenging task. Monitoring ensures the availability of resources before performing successful provisioning. Generally, a central monitor [75] keeps track of the resources in cloud.

The monitor has to query all the resources in the network periodically to get their availability status, which increases network/message overhead. To resolve this, this work suggests to represent cloud as a graph and construct a minimum dominating set structure, which can be used for monitoring resource status. The minimum dominating set structure can minimize the number of message updates made to the monitor and minimize the update time compared to traditional monitoring methods.

How to perform optimal VM placement and migration in CDC for energy-efficient resource provisioning ?

As VM placement has direct impact on the performance of the CDC, this work suggests to optimize VM placement and VM migration for energy-efficient resource provisioning. For optimal VM placement, it suggests to construct KD-tree structure of cloud servers and VMs will be placed on best-fit cloud servers quickly. This KD-tree is a useful structure when search involves a multidimensional search key and it is known as associative search. KD-tree is defined as a tree for storing the values or objects in multidimensional

DOI:

space. They scale well in high dimensions. All the resource dimensions namely CPU, RAM, storage and bandwidth of cloud servers and VM can well be represented using KD-tree structure. Moreover, this structure helps in identifying least loaded PMs easily so that VMs running on it can be migrated to other cloud servers and powered off to conserve energy. [76] constructed one dimensional Binary Search Tree, which considers only single resource dimension, CPU.

How to ensure proper locating of CDCs and allocation of CDCs to the source of requests?

This suggests to model cloud data center network as a graph and use facility location problem to locate CDCs in appropriate locations to serve the source of requests. Limiting the distance between cloud data centers and the source of requests leads to faster service provisioning. [77] has proposed the source of requests assignment to the closest cloud data center to reduce the carbon emission but they modeled cloud data center as a complete graph which is unrealistic. They modelled both the networking and computational components of the infrastructure as a graph and proposed a system which utilizes Voronoi partitions to determine how source requests to be routed to appropriate data center based on the relative priorities of the cloud operator for latency purposes. [52] provided solutions for facility location problems. They have considered distributing the clients to centers as balanced as possible, but they have overlooked the distance between clients and centers, which is also essential for faster service provisioning.

How to cluster distributed CDCs for faster server provisioning?

This suggests to model the cloud environment as a graph and cluster distributed CDCs in order to enable faster service provisioning to the clients. Many works have considered graph-based K-Means [78] and K-Spanning tree [79] clustering methods to cluster a network. In all these approaches the number of clusters K to be created should be known in advance, but determining K is impractical in case of distributed CDCs. Hence, this work suggests to use dominating set based clustering, where each dominating node acts as a cluster head and neighbors are connected to these cluster heads which makes service provisioning fast. The number of clusters (K) to be created is determined based on size of the graph. So, it leads to a non-constrained clustering algorithm.

How to ensure uniform assignment of clients to CDC servers?

This work suggests to use capacitated dominating set concept [51] to assign clients to CDC servers. The capacitated dominating set is the problem of finding a dominating set with the additional constraint that the nodes dominated do not exceed the capacity of the dominating node. The capacity can be uniform across all nodes or variable. Hence, a uniform capacity can be assigned to a homogeneous CDC environment and a variable capacity can be assigned to a heterogeneous CDC environment. For client assignment to CDCs, exiting methods have used Round Robin [80] and its variant approaches, which may not guarantee uniformity all the times.

How to efficiently perform traffic-aware VM migration to load balance cloud servers?

Network flow problem [63] in the form of Maximum flow and Minimum cut problem finds its application in various fields ranging from checking network connectivity, network reliability, namely a few.

This work suggests to use network flow problem by converting cloud into a flow network and to perform traffic-aware live VM migration in order to load balance the cloud servers. Most of the existing benchmarked VM migration approaches [81,82] consider only host-side resource constraints with little consideration on network-side constraints. A good VM migration algorithm which considers both server-side and network-side constraints can greatly improve their performance. This can be done on both live migration or cold migration scenarios.

In network flow problem, a set of path in a graph G is edge-disjoint if each edge in G appears in at most one path. In cloud, some k number of edge-disjoint paths can be computed between overloaded and underloaded servers and can migrate each VM from overloaded server to underloaded server on one of these k paths to perform fast and traffic-aware VM migrations.

Conclusion and Future work

In this paper, an analysis is done on the application of graph theory concepts in computer networks and its suitability to address resource provisioning issues in cloud. In future, we would like to analyze its scope in other research areas of cloud computing.

References

1. Caesar Wu & Rajkumar Buyya. (2015) Cloud Data Centers and Cost Modeling : A Complete Guide To Planning, Designing and Building a Cloud Data Center, 1st Morgan Kaufmann Publishers Inc. San Francisco, CA, USA.

2. Qi Zhang, Lu Cheng and Raouf Boutaba. (2010). Cloud computing: state of-the-art and research challenges, Journal of Internet Services and Applications Springer.

3. David Mitchell Smith, David W. Cearley and Daryl C. Plummer (2009). Key Issues for Cloud Computing, Gartner.

4. Sean Marston , Zhi Li , Subhajyoti Bandyopadhyay , Juheng Zhang and Anand Ghalsasi (2011). Cloud computing — The business perspective, Decision Support Systems, 51,176–189.

5. Bhaskar Prasad Rimal,Eunmi Choi and Ian Lumb (2009). A taxanomy and survey of cloud computing systems, 2009 Fifth International Joint conference on INC,IMS and IDC, IEEE, 44-51.

6. Farrukh Shahzad (2014). State-of-the-art Survey on Cloud Computing Security Challenges, Approaches and Solutions, Procedia Computer Science, 37, 357 – 362.

7. J.A.Bondy&U.S.R.Murty (1976). Graph theory with applications, North Holland,ISBN:0-444-19451-7.

8. Xiaoqiao Meng, Canturk Isci, Jeffrey Kephart, Li Zhang, Eric Bouillet and Dimitrios Pendarakis (2010). Efficient Resource Provisioning in Compute Clouds via VM Multiplexing, ICAC'10, ACM, 11-20.

9. Rajkumar Buyya, Saurabh Kumar Garg and Rodrigo N. Calheiros (2011). SLA-Oriented Resource Provisioning for Cloud Computing: Challenges, Architecture, and Solutions, 2011 International Conference on Cloud and Service Computing.

10. Christian Vecchiola, Rodrigo N. Calheiros , Dileban Karunamoorthy and Rajkumar Buyya (2012). Deadline-driven provisioning of resources for scientific applications in hybrid clouds with Aneka, Future Generation Computer Systems, 28, 58–65.

11. Bahman Javadi, Jemal Abawajy and Rajkumar Buyya (2012). Failure aware resource provisioning for hybrid Cloud infrastructure, Journal of Parallel and Distributed Computing, 72 ,1318–1331.

12. Daniel Warneke, Member and Odej Kao (2011). Exploiting Dynamic Resource Allocation for Efficient Parallel Data Processing in the Cloud, IEEE Transactions on Parallel and Distributed systems, Vol. 22, No. 6.

13. Robert Denz &Stephen Taylor (2013). A survey on securing the virtual cloud, Journal of Cloud Computing: Advances, Systems and Applications, 2-17.

14. Jonathan Stuart Ward and Adam Barker (2014). Observing the clouds: a survey and taxonomy of cloud monitoring, Journal of Cloud Computing: Advances, Systems and Applications , 3-24.

15. Prince Mahajan, Srinath Setty, Sangmin Lee, Allen Clement,Lorenzo Alvisi, Mike Dahlin and Michael Walfish (2011). Depot: Cloud Storage with Minimal Trust, ACM Transactions on Computer Systems, Vol. 29, No. 4, Article 12.

16. S. Subashini and V.Kavitha (2011). A survey on security issues in service delivery models of cloud computing, Journal of Network and Computer Applications, 34, 1–11.

17. Dimitrios Zissis and Dimitrios Lekkas (2012). Addressing cloud computing security

issues, Future Generation Computer Systems, Vol.28, No.3, 583-592.

18. Jyoti Sahni and Deo Prakash Vidyarthi (in press). A Cost-Effective Deadline-Constrained Dynamic Scheduling Algorithm for Scientific Workflows in a Cloud Environment, IEEE Transactions on Cloud Computing.

19. Linjiun Tsai and Wanjiun Liao (in press). StarCube: An On-Demand and Cost-Effective Framework for Cloud Data Center Networks with Performance Guarantee, IEEE Transactions on Cloud Computing.

20. Philipp Waibel, Christoph Hochreiner and Stefan Schulte (2016). Cost Efficient Data Redundancy in the Cloud, 2016 IEEE 9th International Conference on Service-Oriented Computing and Applications,1-9.

21. Makhlouf Hadji, Benjamin Aupeti and Djamal Zeghlache (2016). Cost-Efficient Algorithms for Critical Resource Allocation in Cloud Federations, 2016 5th IEEE International Conference on Cloud Networking,1-6.

22. Kashi Venkatesh Vishwanath and Nachiappan Nagappan (2010). Characterizing Cloud Computing Hardware Reliability, SoCC'10,ACM, 193-204.

23. Deepak Poola, Kotagiri Ramamohanarao and Rajkumar Buyya (2014). Fault-Tolerant Workflow Scheduling Using Spot Instances on Clouds, Procedia Computer Science, Volume 29, 523–533.

24. Sheng Di and Cho-Li Wang (2013). Error-Tolerant Resource Allocation and Payment Minimization for Cloud System, IEEE Transactions on Parallel and Distributed systems, Vol. 24, No. 6.

25. Zibin Zheng, Tom Chao Zhou, Michael R. Lyu and Irwin King (2012). Component Ranking for Fault-Tolerant Cloud Applications, IEEE Transactions on Services computing, Vol. 5, No. 4, 1097 - 1106.

26. Govindrajan A and Lakshmanan (2010). Overview of Cloud standards Cloud computing, vol 0, Springer London, 77-89.

27. Loutas N, E. kamateri and E. Tarabanis (2011). A semantic interoperability framework for cloud platform as a service, IEEE Third International Conference on Cloud Computing Technology and Science, 280-287.

28. Anton Beloglazov, Rajkumar Buyya, Young Choon Lee and Albert Zomaya (2011). A Taxonomy and Survey of Energy-Efficient Data Centers and Cloud Computing Systems, Advances in Computers, Vol.82,Elsevier.47-111.

29. Yuanxiong Guo and Yuguang Fang (2013). Electricity Cost Saving Strategy in Data Centers by using Energy Storage, IEEE Transactions on Parallel and Distributed Systems, Vol. 24, No. 6, 1149-1160.

30. Miyuru Dayarathna, Yonggang Wen and Rui Fan (in press). Data Center Energy Consumption Modeling : A Survey, IEEE Communications Surveys & Tutorials.

31. Anton Beloglazov and Rajkumar Buyya (2010). Energy Efficient Resource Management in Virtualized Cloud Data Centers, 2010 10th IEEE/ACM International Conference on Cluster,Cloud and Grid Computing, 826-831.

32. Young Choon Lee and Albert Y. Zomaya (2010). Energy efficient utilization of resources in cloud computing systems, Journal of Supercomputing, Vol.60, No.2, 268–280.

33. Weizhao Wang, Yu Wang, XiangYang Li, WenZhan Song and Ophir Frieder (2006). Efficient Interference-aware TDMA Link Scheduling for Static Wireless Networks, MobiCom'06, ACM, 262-273.

34. Hiroshi Tamura and Keisuke Nakano (2011). On Applications of Graph/Network Theory to Problems in Communication Systems, ECTI Transactions on Computer and Information Technology, Vol.5, No.1,15-21.

35. Hiroshi Tamura, Masakazu Sengoku and Shoji Shinoda (2008). Edge coloring problem of graph theory considering interference on network coding, The 23rd International Technical conference on Circuits/Systems, Computers and Commnications, 301-304.

36. Khaled M. Alzoubi, Peng-Jun Wan and Ophir Frieder (2002). Message-Optimal Connected Dominating Sets in Mobile Ad Hoc Networks, MOBIHOC’02,ACM,157-164.

37. Christian Scheideler, Andrea W. Richa and Paolo Santi (2008). An O(log n) Dominating Set Protocol for Wireless AdHoc Networks under the Physical Interference Model, MobiHoc’08, ACM, 91-100.

38. Jie Wu and Hailan Li (1999). On Calculating Connected Dominating Set for Efficient Routing in Ad Hoc Wireless Networks, DlAL M 99 Scattlc WA USA ,ACM, 7-14.

39. Kayhan Erciyes, Orhan Dagdeviren, Deniz Cokuslu and Deniz Ozsoyeller (2007). Graph Theoretic Clustering Algorithms in Mobile Ad Hoc Networks and Wireless Sensor Networks Survey, Applied and Computational Mathematics, 6 , no.2, 162-180.

40. Dandan Liu, Xiaohua Jia and Ivan Stojmenovic´ (2007). Quorum and connected dominating sets based location service in wireless ad hoc, sensor and actuator networks, Computer Communications, 30, 3627–3643.

41. Fei Dai and Jie Wu (2004). An Extended Localized Algorithm for Connected Dominating Set Formation in Ad Hoc Wireless Networks, IEEE Transactions on Parallel And Distributed Systems, Vol. 15, No. 10, 908-920.

42. Rashid Bin Muhammad (2007). A Distributed Graph Algorithm for Geometric Routing in Ad Hoc Wireless Networks, Journal of Networks, Vol. 2, No.6, 50-57.

43. Haruko Kawahigashi, Yoshiaki Terashima, Naoto Miyauchi and Tetsuo Nakakawaji (2005). Modeling Ad hoc Sensor Networks using Random Graph Theory, IEEE, 104-109.

44. Prasanta K. Jana and Azad Naik (2009). An Efficient Minimum Spanning Tree based Clustering Algorithm, International Conference on Methods and Models in Computer Science, IEEE.

45. Natarajan Meghanathan (2012). Graph Theory Algorithms for Mobile Ad Hoc Networks, Informatica ,36,185-200.

46. Yuan-Shun Dai and Xiao-Long Wang (in press). Optimal resource allocation on grid systems for maximizing service reliability using a genetic algorithm, Reliability Engineering and system safety, Elsevier.

47. Yuan-Shun Dai, Yi Pan and Xukai Zou (2007). A Hierarchical Modeling and Analysis for Grid Service Reliability, IEEE Transactions on Computers,Vol. 56, No. 5, 681-691.

48. Srikumar Venugopal and Rajkumar Buyya (2006). A Set Coverage-based Mapping Heuristic for Scheduling Distributed Data-Intensive Applications on Global Grids, GRID '06 Proceedings of the 7th IEEE/ACM International Conference on Grid Computing, 238-245.

49. Wenjun Xiao and Behrooz Parhami (2003). Some Conclusions on Cayley Digraphs and Their Applications to Interconnection Networks, GCC 2003,LNCS 3033, Springer-Verlag Berlin Heidelber, 408–412.

50. Jon L.Bentley (1979). Multidimensional Binary Search Trees in Database Applications, IEEE transactions on Software Engineering,Vol.SE-5,No.4,333-340.

51. Anupama Potluri and Alok Singh (2012). A Greedy Heuristic and its Variants for Minimum Capacitated Dominating Set, Proceedings of the International Conference on Contemporary Computing IC3 2012, Communications in Computer and Information Science, vol 306 Springer, Berlin, Heidelberg, 28-39.

52. Judit Bar-Ilan, GuyKortzars and David Pelag (1992). How to allocate network centers, Journal of algorithms, 15, 385-415.

53. Prosenjit Bose, Pat Morin, Ivan Stojmenovi´C and Jorge Urrutia (2001). Routing with Guaranteed Delivery in Ad Hoc Wireless Networks, Wireless Networks 7, 609–616, Kluwer Academic Publishers.

54. YuWang and Xiang-Yang Li (2006). Minimum power assignment in wireless ad hoc networks with spanner property, Journal of Combinatorial Optimization,11: 99–112.

55. Dezun Dong, Yunhao Liu, Kebin Liu and

Xiangke Liao (2010). Distributed Coverage in Wireless Ad Hoc and Sensor Networks by Topological Graph Approaches, IEEE 2010 International Conference on Distributed Computing Systems, 1417-1428.

56. James Newsome and Dawn Song (2003). GEM: Graph EMbedding for Routing and DataCentric Storage in Sensor Networks Without Geographic Information, SenSys'03, ACM, 76-88.

57. Sahan L. Maldeniya, Ajantha S. Atukorale and Wathsala W. Vithanage (2013). Network Data Classification Using Graph Partition, ICON 2013,IEEE.

58. Yuxin Tang, Yunquan Zhang and Hu Chen (n.d.). A Parallel Shortest Path Algorithm Based on Graph-Partitioning and Iterative Correcting, The 10th IEEE International Conference on High Performance Computing and Communications, 155-161.

59. W Xie, M Goyal, H Hosseini, J Martocci, Y Bashir, E Baccelli and A Durresi (2010). Routing Loops in DAG-based Low Power and Lossy Networks, 24th IEEE International Conference on Advanced Information Networking and Applications, 888-895.

60. Guoqi Xie, Renfa Li,Xiongren Xiao and Yuekun Chen (2014). A High-performance DAG Task Scheduling Algorithm for Heterogeneous Networked Embedded Systems, IEEE 28th International Conference on Advanced Information Networking and Applications, 1011-1016.

61. Omair Fatmi and Deng Pan (2014). Distributed Multipath Routing for Data Center Networks based on Stochastic Traffic Modeling, 2014 IEEE 11th International Conference on Networking, Sensing and Control (ICNSC), 536-541.

62. H. Bunke, P. Dickinson, A. Humm, Ch. Irniger and M. Kraetzl (2006). Computer Network Monitoring and Abnormal Event Detection Using Graph Matching and Multidimensional Scaling, ICDM 2006, LNAI 4065, Springer-Verlag Berlin Heidelberg, 576–590.

63. Kiyoshi Nakayama and Toshio Koide (2013). A Decentralized Algorithm for Network Flow Optimization in Mesh Networks, Globecom 2013-Communication QoS, Reliability and Modeling symposium, IEEE, 1532-1537.

64. Wang X, Tiropanis T and Davis H.C (2012). Evaluating Graph Traversal Algorithms for Distributed SPARQL Query Optimization, The Semantic Web. JIST 2011. Lecture Notes in Computer Science,. Springer, Berlin, Heidelberg, vol 7185,210-225.

65. N. Lakshmi prasanna K. Sravanthi and Nagalla Sudhakar (2014). Applications of Graph Labeling in Major Areas of Computer Science, International Journal of Research in Computer and Communication Technology, Vol 3, Issue 8, 819-823.

66. Ümit V. Çatalyürek, Kamer Kaya and Bora Uçar (2011). Integrated Data Placement and Task Assignment for Scientific Workflows in Clouds, DIDC'11 fourth international workshop on Data-intensive distributed computing, ACM,45-54.

67. Yuan-Shun Dai , Bo Yang , Jack Dongarra and Gewei Zhang (n.d.). Cloud Service Reliability: Modeling and Analysis , Innovative Computing Laboratory, Department of Electrical Engineering & Computer Science, University of Tennessee, Knoxville, TN, USA,1-17.

68. Tim Verbelen , Tim Stevens, Filip De Turck and Bart Dhoedt (2013). Graph partitioning algorithms for optimizing software deployment in mobile cloud computing, Future Generation Computer Systems, 29,451–459.

69. Min Li, Dinesh Subhraveti, Ali R. Butt, Aleksandr Khasymski and Prasenjit Sarkar (2012). CAM: A Topology Aware Minimum Cost Flow Based Resource Manager for MapReduce Applications in the Cloud, HPDC '12 21st international symposium on High-Performance Parallel and Distributed Computing, ACM , 211-222.

70. Tobias Binz, Christoph Fehling, Frank Leymann, Alexander Nowak and David Schumm (2012). Formalizing the Cloud through Enterprise Topology Graphs, IEEE Fifth International Conference on Cloud Computing, 742-749.

71. Nikhil Bansal, Kang-Won Lee, Viswanath Nagarajan and Murtaza Zafer (2011). Minimum Congestion Mapping in a Cloud, PODC '11 30th annual ACM SIGACT-SIGOPS symposium on Principles of distributed computing , 267-276.

72. W.K. Chan, Lijun Mei and Zhenyu Zhang (2009). Modeling and Testing of Cloud Applications, IEEE APSCC 2009, 111-118.

73. Zhiping Peng, Bo Xu, Delong Cui, Weiwei Lin and XuAn Wang (2015). Deployment method of virtual machine cluster based on energy minimization and graph cuts theory, 10th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing, 800-803.

74. D. P. Zegzhda and A. V. Nikolsky (2014). Formal Security Model for Virtual Machine Hypervisors in Cloud Computing Systems, Nonlinear Phenomena in Complex Systems, Vol. 17, No. 3, 253 - 262.

75. Galstad,E [Online]. Nagios NRPE Documentation,http://nagios.sourceforge.net/docs/nrpe/NRPE.pdf,(Accesssed 2016).

76. Sameer Kumar Mandal and Pabitra Mohan Khilar (2013). Efficient Virtual Machine Placement for On-Demand Access to Infrastructure Resources in Cloud Computing, International Journal of Computer Applications, Vol.68, No.12, 0975–8887.

77. Joseph Doyle, Robert Shorten and Donal O'Mahonym (2013). Stratus: Load Balancing the Cloud for Carbon Emissions Control, IEEE Transactions on Cloud Computing, Vol.1**,** No**.**1, 116-128.

78. Laurent Galluccio, OlivierMichel, PierreComon and Alfred O.Hero (2012). Graph based K-means clustering, Signal Processing, Elsevier, Vol.92,No. 9, 1970-1984.

79. Yan Zhou, Oleksandr Grygorash and Thomas F. Hain (2011). Clustering With Minimum Spanning Trees, International Journal on Artificial Intelligence Tools, World Scientific Publishing Company, Vol.20, No.1, 139–177.

80. Radojević, Branko and Mario Žagar (2011). Analysis of issues with load balancing algorithms in hosted (cloud) environments, MIPRO, 2011 Proceedings of the 34th International Convention, IEEE, 416-420.

81. Gunjan Khanna, Kirk Beaty, Gautam Dhar and Andrzej Kochu (2006). Application performance management in virtualized server environments, Proceedings of the Network Operations and Management Symposium NOMS 10th IEEE/IFIP, 373-381.

82. Timothy Wood, Prashant Shenoy and Arun (2007). Black-box and gray-box strategies for virtual machine migration, Proceedings of the 4th USENIX Symposium on Networked Systems Design and Implementation, 229-242.