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# Simulation modeling of cloud computing for smart grid using CloudSim

Sandeep Mehmi [a,*], Harsh K. Verma [b], A.L. Sangal [b]

[a] Department of Computer Science and Engineering, Punjab Technical University, Punjab, India

[b] Department of Computer Science and Engineering, Dr. B.R Ambedkar National Institute of Technology, Jalandhar, India

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**Abstract**

In this paper a smart grid cloud has been simulated using CloudSim. Various parameters like number of virtual machines (VM), VM Image size, VM RAM, VM bandwidth, cloudlet length, and their effect on cost and cloudlet completion time in time-shared and space-shared resource allocation policy have been studied. As the number of cloudlets increased from 68 to 178, greater number of cloudlets completed their execution with high cloudlet completion time in time-shared allocation policy as compared to space-shared allocation policy. Similar trend has been observed when VM bandwidth is increased from 1 Gbps to 10 Gbps and VM RAM is increased from 512 MB to 5120 MB. The cost of processing increased linearly with respect to increase in number of VMs, VM Image size and cloudlet length.



*Keywords:* Smart grid; Cloud computing; CloudSim; Virtual machine; Cloudlet completion time

## 1. Introduction

Electricity is delivered from suppliers to consumers through an interconnected network called Grid. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers (Kaplan, 2009). Power Grid India (Power Grid Corporation of India, 2016) has described India as world's 3rd largest transmission utility, yet it faces challenges like inadequate access to electricity, supply shortfalls (peak and energy), poor quality and reliability, and rampant theft. The objective to make the traditional grid infrastructure efficient, automated, intelligent and robust has provided impetus to the development of smart grid (SG). Power grids are real-time power delivery systems where power generation, transmission and distribution functions are required to be executed simultaneously. Inability to

* Corresponding author.

*E-mail addresses:* sandeep.mehmi@gmail.com (S. Mehmi), vermah@nitj.ac.in (H.K. Verma), sangalal@nitj.ac.in (A.L. Sangal).

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store power on large scale poses another challenge to this system. So, supply and demand must be balanced at every instant which is possible only through quick decisions based on analysis of real time data generated by smart grid. The intelligent monitoring sensors generate enormous heterogeneous, uncorrelated and unstructured data which need large number of scalable storage servers. The analytic tools and optimization algorithms require reliable computation servers to perform self-healing, fault tolerance, load balancing, demand response and optimal power flow functions. Furthermore, the customer web applications need designing and deployment tools for displaying real-time consumption patterns, flexible tariffs and online bill payments. The lack of necessary computing infrastructure in existing setup and financial constraints are the primary challenges for full realization of complex smart grid in developing countries like India. Traditional methods of using centralized expensive servers, storage hardware disk arrays, relational database management system and tightly coupled business application software package lead to poor system scalability, high cost and poor reliability. On the other hand, cloud computing can help in building smart grid cloud that has the ability to meet the requirements of data and computing intensive smart grid applications. Through the application of cloud computing model, smart grid can enhance the reliability, availability, safety, efficiency and environment friendliness in power sector.

In this paper cloud computing model for smart grid has been simulated using CloudSim. The effect of variation in parameters like number of virtual machines (VM), VM Image size, RAM size, VM bandwidth and cloudlet length on total cost of processing and cloudlet completion time has been studied. The time-shared and space-shared allocation policies have been utilized at hosts and VM level in order to evaluate their effect on cloudlet completion time. This research is beneficial for developing nations particularly the Indian government for developing smart grid cloud, evaluating the cloud infrastructure requirements for hosting smart grid applications, determining the VM/cloudlet parameters, and prediction of cost and time for processing the smart grid tasks.

The remaining paper is organized as follows. In Section 2, the background and related work has been presented. The methodology of research has been discussed in Section 3. The simulation modeling of the smart grid cloud has been presented in Section 4. Section 5 covers the result and discussions. Finally this paper is concluded in Section 6.

## 2. Background and related work

Smart grid technology is gradually transforming the way electrical power is produced and consumed (Abdelsalam and Abdelaziz, 2014). Smart grid can be defined as an interconnected system of information communication technologies and control systems. It has the ability to interact with automation and business processes across the entire power sector, encompassing electricity generation, transmission, distribution and the consumer (FICCI, 2016). The smart grid is considered a critical information infrastructure (CII), the incapacitation or destruction of which, shall have debilitating impact on national security, economy, public health and safety. The NIST's reference model has divided the smart grid into seven domains: customers, markets, service providers, operations, bulk generation, transmission and distribution (NIST, 2016a). Some of smart grid initiatives around the world include (Smart Grid Vision, 2016): US Department of Energy (DOE)-GRIDTECH Team's new vision of targeting 80% renewable and 100% consumer participation by 2035. NY State Smart Grid Consortium has formulated a roadmap which estimated that an investment of $7.2 billion will result in savings and avoided costs to customers of $18.9 billion during the period 2011–2025. In Canada, some of implemented Government funded projects include: Transmission Dynamic Line Rating on an 115 kV line of Manitoba Hydro and Ontario Smart Metering Initiative (4.5 million meters in Hydro One and Wide Area Control System at Hydro Quebec). In UK, ENSG, a Government body, has formulated a 40 year Route map (2010–2050). The drivers are cost effective transition to low carbon economy, energy security, affordability and economic competitiveness. In France, Electricité Réseau Distribution France (ERDF) has formulated plans for roll-out of several smart grid projects which include: Linky Grid (Geographical information system, MV/LV Grid operation management, Network modernization, Power quality) and Grid4EU (2011–2015). The Grid4EU project will include 6 major European utilities, 28 partners and 6 pilot projects. In Germany, DKE has formulated a smart grid standard development road map (2010–2013) which has given elaborated recommendations in areas of general, regulatory & legislative changes, security & privacy, communications, architecture & power automation, distribution system automation, smart metering, distributed generation (DG) & virtual power plants, electro-mobility, storage, load management (DR), and home automation. Germany has estimated the smart grid investment of €40 billion by 2020. In Italy, Ministry of Economic Development has granted over EUR 200 million for demonstration of smart grid features and network modernisation in southern regions. In China, Govrernment run State Grid Corporation of China leads the smart grid development with a funding of USD 7.5 billion in 2010. China envisions a strong smart grid covering 8 domains (planning, generation, transmission, transformation, distribution, consumption, dispatching and ICT); 26 technical areas and 92 standards series.

Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (NIST, 2016b). It is the new way of computing where the processing, storage and network power is delivered as service over the internet. Cloud computing has evolved due to the advances in field of hardware (hardware virtualization, multi-core chips), internet technologies (web services, SOA, web 2.0), distributed computing (grid computing) and system management (autonomic computing, data center automation). It has taken a huge leap from a small business concept to fastest growing sector in IT industry in considerably short span of time. Cloud computing services can be categorized into three classes, according to the abstraction level of the capability provided and the service model of providers, namely: (1) Infrastructure as a Service (IaaS), (2) Platform as a Service (PaaS), and (3) Software as a Service (SaaS) (Buyya et al., 2011). IaaS provides infrastructure e.g servers, network devices, firewall, load balancer and storage disks to users/organizations as a service on demand. IaaS helps the organizations to host their applications, monitor traffic and keep them running $24 \times 7$ without worrying about spikes in infrastructure demand. IaaS is particularly beneficial for small and medium-sized business enterprises that can access server and storage systems through pay-per-use model, which they would otherwise have to purchase (Microsoft, 2016). The consumer need not manage or control the cloud infrastructure but has control over operating systems, storage, deployed applications; and possibly limited control of selected networking components (e.g., host firewalls) (NIST, 2016b). The access to the cloud is provided through various user interfaces, the most common being Web service application programming interface (API), command-line interfaces (CLI) and graphical user interfaces (GUI), which provide different level of abstraction. The cloud infrastructure is built and distributed around the world with considerable degree of data redundancy, so that the failure of one site does not affect the overall service, ensuring the responsiveness and availability of service. In order to overcome the spikes in demand, the features- automatic scaling and load balancing allow distribution of the traffic to available servers. The middle layer also called Platform-as-a-Service (PaaS), provides services as an environment for programming (e.g., Django) or software execution (e.g., Google App Engine). The consumers can choose from various libraries, mashup editors, frameworks, and tools to deploy their applications onto the cloud. PaaS offers various programming models to solve particular problems (e.g., MapReduce model for processing large volume of data in cluster of computers and Workflow model for orchestration of business processes in form of work-flows). PaaS providers also offer various languages and frameworks (e.g., .NET for Microsoft Windows Azure; Python and Java for App Engine; Ruby on Rails for Heroku; Perl, PHP, C++, Java, Hive for Amazon Elastic MapReduce and Apex for Force.com) to support variety of customer applications. Applications like video processing, social networks and customer relationship management, residing on the top of the cloud stack (SaaS), can be accessed through thin client interface such as web browsers. SaaS restricts the customer requirements by merely offering software applications as a service (Xiao and Xiao, 2012). SaaS providers deliver the software in a “one to many” model which is managed form central location. The users need not handle the underlying cloud infrastructure, software upgrades and patches for running their applications.

The proposed cloud for smart grid has been implemented using CloudSim. CloudSim is a new, generalized, and extensible simulation framework that enables seamless modeling, simulation and experimentation of emerging cloud computing infrastructures and application services (Buyya et al., 2009). It enables the modeling of datacenter, hosts, VMs, cloudlets and brokers. Datacenter is composed of same or varied configuration hosts (servers). The host in a datacenter is characterized by host id, RAM, storage, bandwidth, processing power (MIPS) and number of processing elements (PE). The hosts are responsible for managing the VM creation, VM migration, VM destruction and VM provisioning. The allocation of VMs to host depends upon the allocation policy adopted by VM provisioner, default policy being first come first serve. The applications or cloudlets are handled by VMs that are allocated a share of processing power and memory on datacenter hosts. The number of VMs created on a host depends upon the VM RAM. The VMs are characterized by image size, RAM, processing power, bandwidth and number of PEs while the cloudlets are characterized by length, file input size and file output size. For task or cloudlet mapping to VM, the host utilizes the time-shared or space shared allocation policy. The difference between the two policies can be demonstrated by taking an example of cloud having a host with two PEs, receiving request for hosting two VMs such that each VM requires two PEs. Furthermore, each VM has to execute four cloudlets such that c1–c4 to be run in VM1, while c5–c8 to be run in VM2. In cloud utilizing space-shared allocation policy at both host and VM level: as each VM requires two PEs, only one VM can be mapped to host at a given instance of time. Only when VM1 completes the execution of its cloudlets, VM2 is allowed to execute its cloudlets on host's PE. Similar policy is implemented for cloudlets hosted within the VM, as each cloudlet requires one PE therefore two cloudlets can run simultaneously, making other two to wait until the completion of earlier cloudlets. When time-shared allocation policy is applied at both host and VM level: the PE's are concurrently shared by the VMs and the shares of each VM are concurrently divided among the cloudlets assigned to each VM. In this case, there are no waiting queues either for VMs or for cloudlets. The brokers are mediators between the users and the cloud service providers (CSP). Each CSP registers itself and the status of its resources with the cloud information service (CIS), a database of all the CSP. The broker maps the user requests to appropriate CSP such that the Quality of service (QoS) requirements in terms of response time and budget, as demanded by the user, are met. The cloud coordinator in a datacenter holds the responsibility for checking the datacenter load, communication with the cloud coordinators of federation, and load migration to other clouds. The cloud market is simulated by associating the cost per memory, cost per storage, cost per bandwidth and processing cost with the datacenter. The VM creation for applications will incur memory and storage costs while the bandwidth costs will incur during the transfer of data. If no task is executed on VM after latter's creation then only cost of storage and memory will only be charged from user.

There have been several studies on how smart grid applications can exploit cloud computing to increase their reliability and performance (Markovic et al., 2013). A smart grid cloud for Indian Power Sector has been proposed (Mehmi et al., 2014a). The smart grid cloud fetched the data from bulk power generation centers, transmission substations, distribution substations, markets and subsequently performed functions namely data storage, distribution operation & control, transmission operation & control, distributed generation operation & control, computational intelligence based self-healing, fault tolerance and demand side management (Mehmi et al., 2014b). Economic viability of cloud based smart grid and analysis of cloudlet completion time during attack have also been discussed (Mehmi et al., 2015, 2016a,b). Yigit et al. have discussed the smart grid and cloud computing architectures, cloud platform's technical & security issues, and opportunities & challenges for cloud platforms in implementing smart grid applications (Yigit et al., 2014). In another study, Dong et al. have studied the characteristics of service oriented architecture (SOA), business process technology and discussed on how to use them to build a Smart Power Utilization Service System (SPUSS) (Dong et al., 2012). Based on simulation techniques, Mohsenian-Rad and Leon-Garcia (2010) have shown that a grid-aware service request routing design in cloud computing can significantly help in load balancing which can make the grid more reliable and more robust with respect to link breakage and demand-supply variations.

After reviewing the above literatures, we have found following research gaps: (1) The simulation of cloud for smart grid applications has not been suitably addressed. (2) The empirical research on cost and time analysis for processing the smart grid applications is missing. (3) Inadequate research has been devoted to explore the effect of various cloud parameters pertaining to hosts, VMs and cloudlets on cloudlet completion time. This research paper distinguishes itself from researches cited above by addressing the unique requirements of this domain.

## 3. Methodology

The following methodology has been adopted in this research:

- The cloud is simulated for smart grid of India run by Powergrid Corporation of India having intra city network in 68 cities and point of presence in 178 cities.
- The coding has been done to model data center with 2 servers. The number of VM is equal to number of cities i.e. 68. However, the data center has enough RAM, bandwidth and storage specifications to accommodate data from 178 cities. The number of servers, their RAM, bandwidth and storage specifications can further be increased as per demand.
- Tasks in form of cloudlets are fetched from thin clients. So, minimum configuration for cloudlet length and file size has been assumed.
- Simulation has been done to accommodate cloudlets from maximum of 178 cities/centers. The VM Image size, VM RAM, VM MIPS, VM bandwidth and cloudlet length parameters have been varied accordingly.
- The above variations are studied in two VM provisioning policies: time-shared and space-shared.
- The effect of variations of above parameter on cost of processing and cloudlet completion time has been measured.

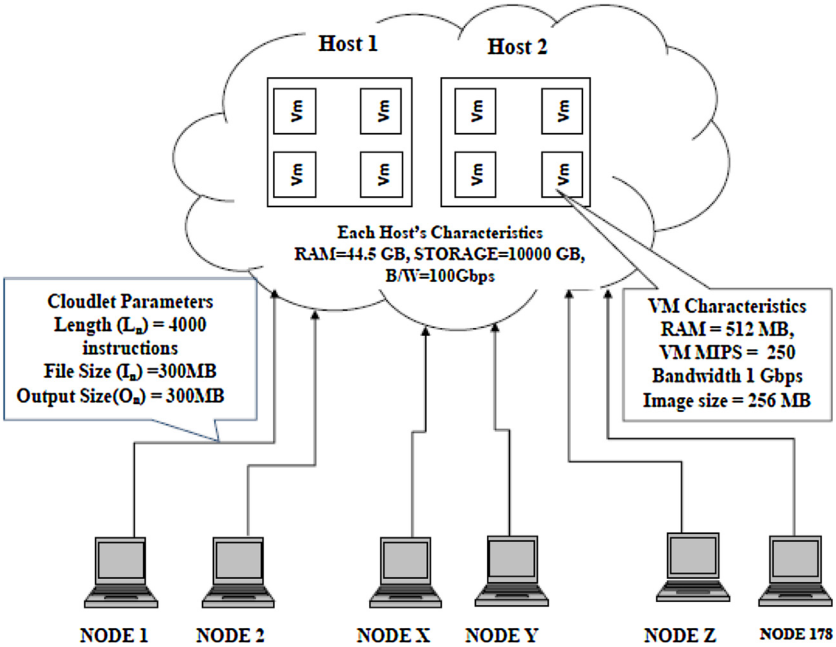


Fig. 1. Smart grid cloud model.

## 4. Simulation modeling using CloudSim

Power Grid Corporation Of India Limited (POWERGRID), the Central Transmission Utility (CTU) of the country under Ministry of Power is one among the largest Power Transmission utilities in the world. The company has intra city network in 68 cities and point of presence in approximately 178 cities (Power Grid Corporation of India, 2016). In the experiments, cloud is simulated for POWERGRID and service from 1 CSP or 1 datacenter is taken. The number of hosts/servers created on each data center is two, where each host has following configuration: RAM = 44.5 GB, storage = 10,000 GB and bandwidth = 100 Gbps. Each VM has following characteristic: RAM = 512 MB, processing power = 250 MIPS, bandwidth = 1 Gbps and image size = 256 MB. The cloudlets have the characteristics: file size = 300 MB and output file = 300 MB. The smart grid cloud model is shown in Fig. 1. The number of cloudlets and VMs are varied from 68 to 178 to evaluate the effect on time and cost.

The class design detail for CloudSim has been depicted in Fig. 2. The finer details related to the simulation process and the various parameters related to simulation model are discussed as under:

### *4.1. Datacenter*

The class *Datacenter* is responsible for creating the core infrastructure services that are required for smart grid cloud. It can model servers having same or diverse RAM, storage and bandwidth characteristics. Furthermore, every Datacenter component instantiates a generalized application provisioning component that implements a set of policies for allocating bandwidth, memory, and storage devices to hosts and VMs.

### *4.2. DatacenterCharacteristics*

This class contains configuration information of datacentre resources. In this research, service from 1 CSP or 1 Datacenter is taken to create smart grid cloud.

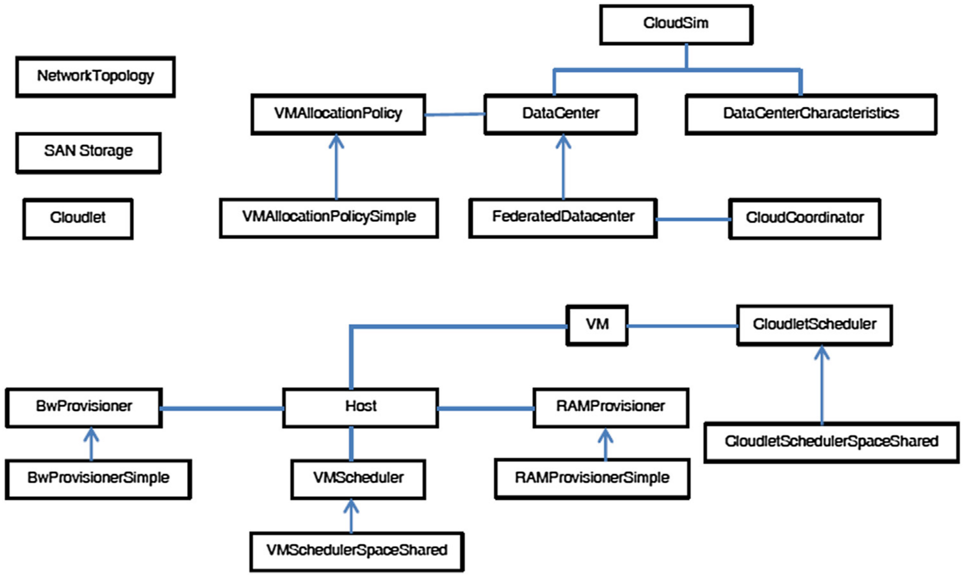


Fig. 2. The class design for CloudSim.

### 4.3. Host

This class is responsible for modeling a physical resource such as a compute or storage server. It encapsulates important information such as the amount of memory and storage, type of processing cores (to represent a multi-core machine), an allocation policy for sharing the processing power among VMs, and policies for provisioning memory and bandwidth to the VMs. In our research, 2 hosts/servers are created on datacenter where each host has following configuration: RAM = 44.5 GB, storage = 10,000 GB and bandwidth = 100 Gbps.

### 4.4. CloudCoordinator

This abstract class extends a cloud-based datacenter to the cloud federation. CloudCoordinator monitors the internal state of datacenter resources and takes load balancing decisions accordingly. Monitoring of datacenter resources is performed by the *updateDatacenter()* function. User can configure their own inter cloud provisioning policies by extending this class. Our simulation model only takes service form 1 datacenter.

### 4.5. Vm

This class models a VM, which is managed and hosted by a Cloud host component. Vm class stores the characteristics like RAM, image size, no. of CPU cores, bandwidth and VM's internal provisioning policy. In smart grid cloud model, no. of VM created is equal to no. of cities in smart grid and each VM has following characteristic: RAM = 512 MB, processing power = 250 MIPS, bandwidth = 1 Gbps and image size = 256 MB

### 4.6. VmAllocationPolicy

This abstract class represents a provisioning policy that a VM Monitor utilizes for allocating VMs to hosts. The objective of the VmAllocationPolicy is to select the available host in a datacenter that meets the memory, storage, and availability requirement of a VM. *VmAllocationPolicySimple* has been utilized in our experiments.

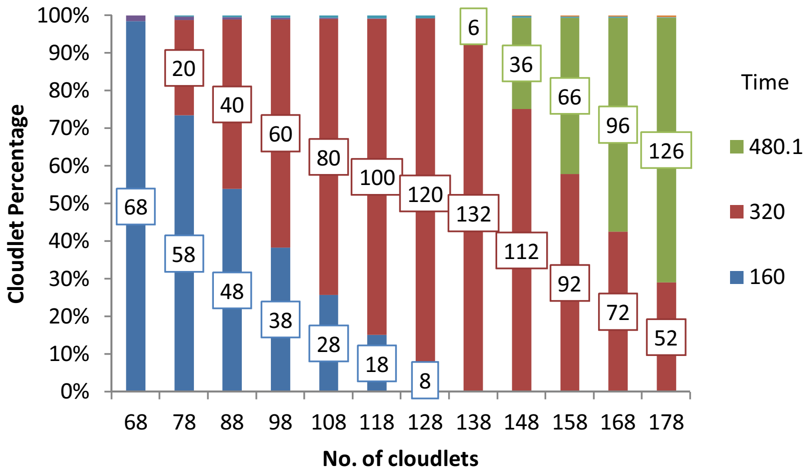


Fig. 3. Number of cloudlets vs cloudlet completion time (time-shared allocation policy).

### 4.7. *VmScheduler*

This is an abstract class implemented by a Host component that models the policies (space-shared, time-shared) required for allocating processor cores to VMs. In our experiments both *VmSchedulerSpaceShared* and *VmScheduler-TimeShared* mapping policies have been utilized.

### 4.8. *Cloudlet*

This class represents the tasks that are to be uploaded on to the cloud for processing. Every cloudlet has a pre-assigned instruction length and data transfer (both pre and post fetches) overhead that it needs to undertake during its life cycle. In our simulation model the cloudlets have following characteristics: cloudlet length = 40,000 MIPS, file size = 300 MB and output file size = 300 MB.

### 4.9. *BwProvisioner*

This is an abstract class that models the policy for provisioning of bandwidth to VMs. The main role of this component is to undertake the allocation of network bandwidths to a set of competing VMs that are deployed across the data center. Cloud system developers and researchers can extend this class with their own policies (priority, QoS) to reflect the needs of their applications. In this research *BwProvisioningSimple* has been utilized which provides as much bandwidth as required by VM; however, this is limited by the total available bandwidth of the host.

### 4.10. *CloudletScheduler*

This abstract class is extended by the implementation of different policies that determine the share of processing power among Cloudlets in a VM. We have utilized both time-shared policy and space-shared policy (*CloudetSched-ulerTimeShared* and *CloudetSchedulerSpaceShared*) in our experiments.

The cloud computing model for smart grid has been simulated on Intel Core i3–370 M Processor, 2.40 GHz machine having 3 MB of L3 Cache and 2 GB of RAM running Windows 7 Professional, NetBeans IDE 7.3 and CloudSim Toolkit 3.0.

## 5. Results and discussions

Fig. 3 illustrates the effect of number of cloudlets (n) on their respective cloudlet completion time in time-shared scheduler policy. With the host, VM and cloudlet configuration remaining constant, as ‘n’ is increased from 68 to

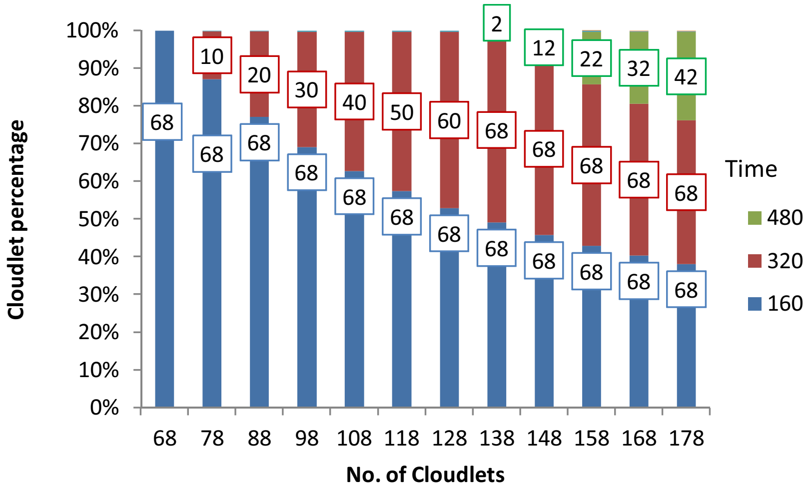


Fig. 4. Number of cloudlets vs cloudlet completion time (space-shared allocation policy).

178, the time taken by the cloudlets for task completion also increased. At n = 68, 100% of cloudlets complete their processing in time = 160 s while at n = 128, only 6% of cloudlets complete their processing in t = 160 s and remaining 94% cloudlets complete their processing in 320s. Similarly at n = 178, none of cloudlet completed its processing in 160 s while maximum of 29% of cloudlets and 71% of cloudlets completed their processing in 320 s and 480.1 s respectively.

Fig. 4 illustrates the effect of number of cloudlets on their respective cloudlet completion time in space-shared allocation policy. With the host, VM and cloudlet configuration remaining constant, as 'n' is increased from 68 to 178, the number of cloudlets completing their processing in 160 s decreased from 100% to 38%, the number of cloudlets completing their processing in 320 s increased from 0% to 38% and the number of cloudlets completing their processing in 480 s increased from 0% to 24%. At n = 68, 100% of cloudlets completed their processing in 160 s while at n = 128, only 53% of cloudlets completed their processing in 160 s and rest of 47% cloudlets completed processing in 320s. Similarly at n = 178, 38% of cloudlets completed their processing in 160s, another 38% of cloudlets in 320 s and rest of 24% of cloudlets completed their processing in 480 s.

The comparison of cloudlet completion time between time-shared and space-shared allocation policy indicates that the number of cloudlets, completing their processing with high cloudlet completion time is greater in time-shared allocation policy than space-shared allocation policy. This is due to the fact that in time-shared allocation policy, each VM receives a time slice on each processing core and similarly the cloudlets dynamically context switches during the VM lifetime. Multiple VM can simultaneously multi-task within host and similarly multiple cloudlets can simultaneously multi-task within a VM. While in case of space-shared allocation policy the host is exclusively allocated to VM till latter's completion. Similarly cloudlets are assigned a VM such that at one instant only one cloudlet will be actively using the VM. These results also imply that the high cloudlet completion time has been obtained in time-shared allocation policy despite the presence of waiting time, incurred during space-shared allocation policy.

Fig. 5 shows the effect of number of VM on the cost of processing. With the host, VM and cloudlet characteristics remaining constant, as the number of VMs increased from 68 to 178 the cost of processing also increased from $3481.6 to $9113.6. The reason for increase in cost of processing can be associated with cost incurred during VM creation. Whenever new VM is created, memory and storage costs will incur.

Fig. 6 shows the effect of Cloudlet length (l) on the maximum processing time. With the host, VM and cloudlet characteristics remaining constant, as 'l' increased from 40,000 instructions to 160,000 instructions, the maximum processing time also increased from 160 s to 640 s. The cloudlet completion time is the function of cloudlet length and capacity of the host. As the number of instruction in a cloudlet is increased, more data will be transferred to VM and hence host will take more time to execute the cloudlet.

Fig. 7 shows the effect of VM image size on the cost of processing. As the VM image size is increased from 256 MB to 2048 MB, the cost of processing also increased from $3481.6 to $15,667.2 and from $9113.6 to $41,011.2 for number of VM = 68 and 178 respectively. When the VM is initiated, the memory and storage costs will be incurred. The cost

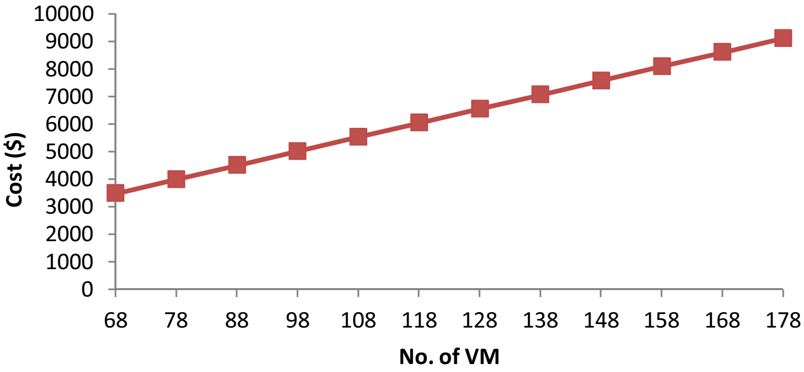


Fig. 5. No. of VM's vs Cost.

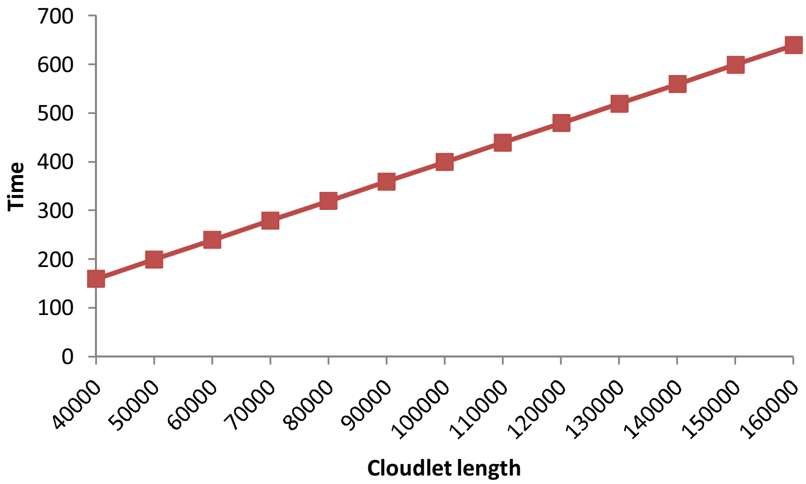


Fig. 6. Cloudlet length vs maximum processing time.

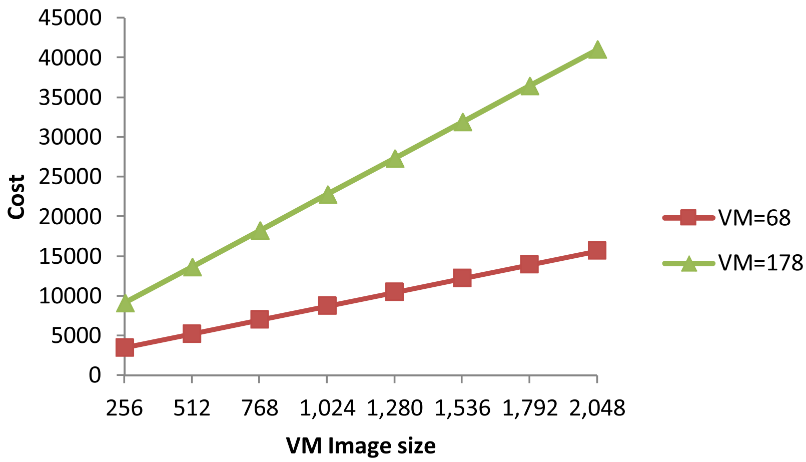


Fig. 7. VM image size vs cost.

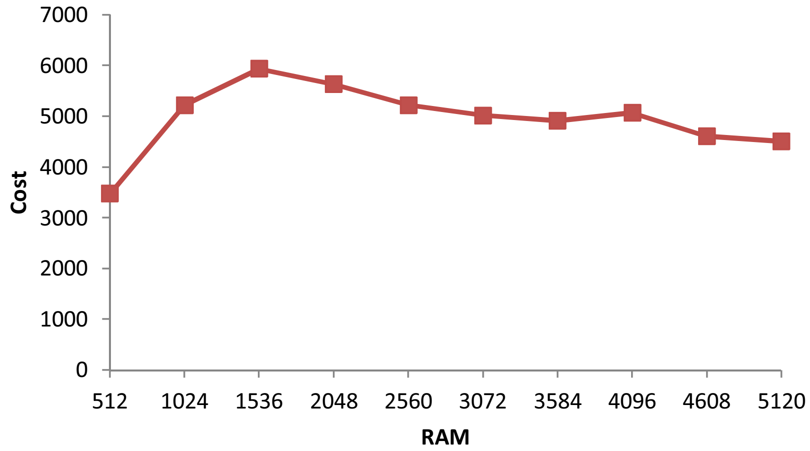


Fig. 8. VM RAM vs cost of processing.

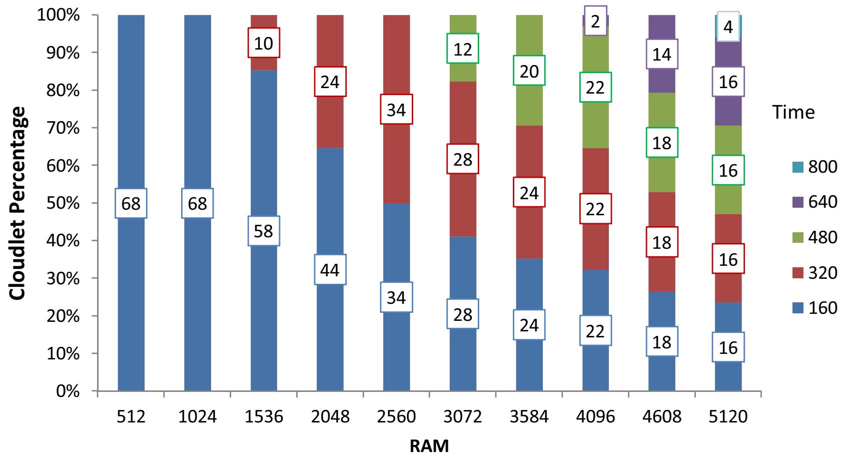


Fig. 9. VM RAM vs cloudlet completion time (space-shared allocation policy).

is a function of VM Image size. The linear increase in cost with respect to increase in VM Image size is associated with larger operating system, data files and applications that are used when VM runs.

Fig. 8 illustrates the effect of VM RAM on total cost of processing. The cost of processing showed upward trend from \$3481.6 to \$5939.2 for increase of RAM from 512 MB to 1536 MB, further downward trend upto \$4915.2 with further increase of RAM upto 3584 MB. The reason behind this trend can be summarized as: (a) Larger the VM's RAM, costlier it will be. (b) The total cost includes the VM creation costs (storage and memory) and processing costs (transfer of data). The increase in total cost till 1536 MB RAM can be linked to high bandwidth/processing cost incurred, as compared to VM creation costs. (c) Decrease in total cost with further increase in RAM can be correlated with high VM creation cost as compared to bandwidth cost. (d) The resultant total cost is greater in case (c) than case (d).

Fig. 9 shows effect of VM RAM on cloudlet completion time in space-shared allocation policy. Cloudlet completion time varied significantly along with RAM. At n = 68, when RAM increased from 512 MB to 5120 MB, number of cloudlets completing task in 160 s decreased from 100% to 23.53%, number of cloudlets completing task in 320 s increased from 0% to 50% (at RAM = 2560MB) then decreased to 23.53% (at RAM = 5120 MB), the percentage of cloudlets completing task in 480 s remained zero upto 2560 MB, increased from 17.65% (at RAM = 3072) to 32.35% (at RAM = 4096) then decreased to 23.53% (at RAM = 5120 MB). Similarly the percentage of cloudlets completing task in 640 s increased from 2.3% (at RAM = 4096 MB) to 23.53% (at RAM = 5120 MB). The cloudlets completing their task in 800 s made their mark at RAM = 5120 MB with 5.88%.

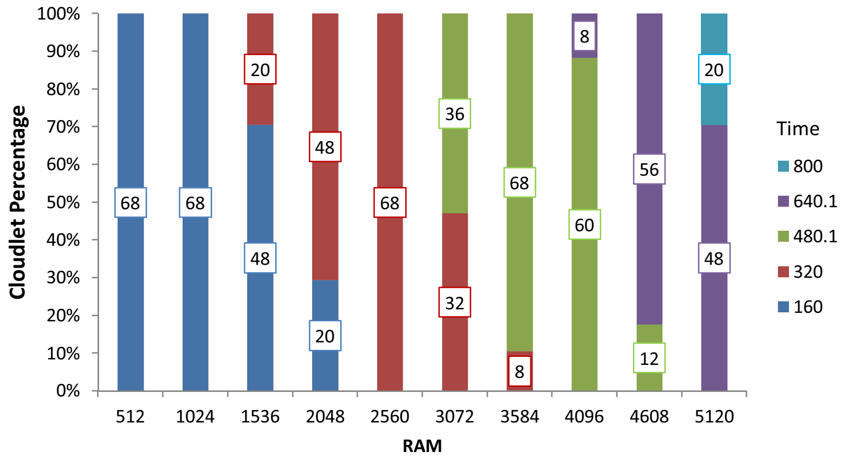


Fig. 10. VM RAM size vs cloudlet completion time (time-shared allocation policy).

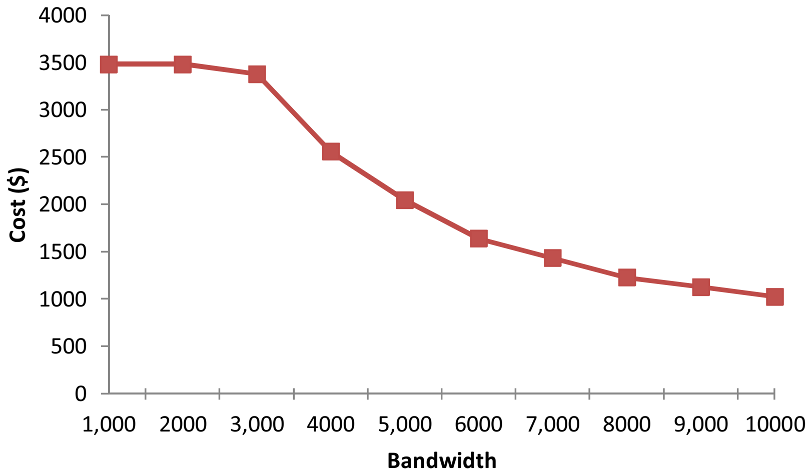


Fig. 11. Bandwidth vs cost.

Fig. 10 shows the effect of VM RAM on cloudlet completion time in time-shared allocation policy. At n = 68, as the VM RAM increased from 512 MB to 5120 MB, the following variations in cloudlet completion time have been noted: (a) the time taken by cloudlets to complete the task increased, (b) Mostly, the cloudlets exhibited two type of completion time variations at each RAM input.

The comparison of cloudlet completion time, with respect to VM RAM, between time-shared and space-shared allocation policy reveals that the number of cloudlets completing their execution with high cloudlet completion time is greater in time-shared allocation policy than space-shared allocation policy. The logic behind this trend can be linked to the fact that in time-shared allocation policy, host is concurrently shared by the VMs and the shares of each VM are simultaneously divided among its task units. While in space-shared allocation policy, only when one VM completes it execution on host, other VM is allowed to run its cloudlets on the host.

Fig. 11 shows the plot of VM bandwidth against maximum cost of processing. The cost of processing decreased from $3481.6 to $1024 as the VM bandwidth increased from 1 Gbps to 10 Gbps. The reason behind this trend can be linked to the fact that high optimization of host-VM density and I/O operations is achieved with increased VM bandwidth. Besides, the cost incurred during the data transfer decreases with increase of VM bandwidth.

Fig. 12 shows effect of VM bandwidth on cloudlet completion time in space-shared allocation policy. Cloudlet completion time varied significantly along with VM bandwidth. With n = 68, when VM bandwidth increased from 1 Gbps to 10 Gbps, number of cloudlets completing task in 160 s decreased from 100% to 29.41%, number of cloudlets com-

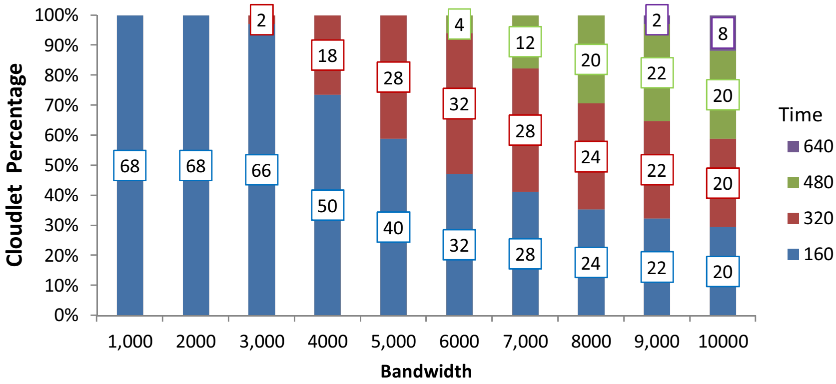


Fig. 12. Bandwidth vs cloudlet completion time (space-shared allocation policy).

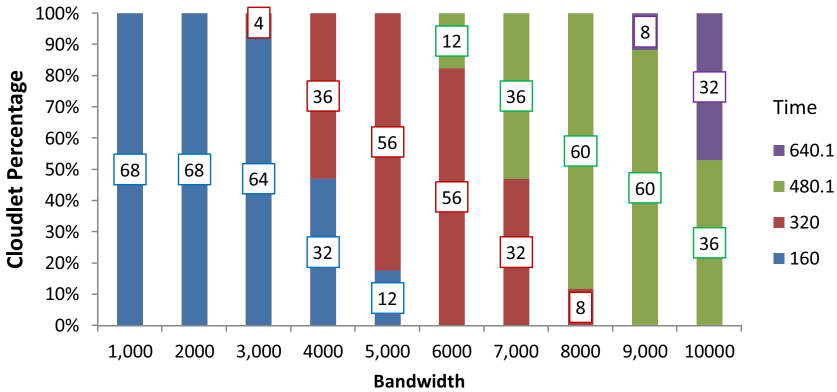


Fig. 13. Bandwidth vs cloudlet completion time (time-shared allocation policy).

pleting task in 320 s increased from 0% to 47.06% (highest at bandwidth = 6 Gbps) then decreased to 29.41% (lowest at bandwidth = 10 Gbps). The percentage of cloudlets completing task in 480 s remained zero upto 6 Gbps, increased from 5.89% (at bandwidth = 6 Gbps) to 32.35% (at bandwidth = 9 Gbps) then decreased to 29.41% (at bandwidth = 9 Gbps). Similarly the percentage of cloudlets completing task in 640 s increased from 2.94% (at bandwidth = 9 Gbps) to 11.76% (at bandwidth = 10 Gbps).

Fig. 13 depicts the effect of VM bandwidth on cloudlet completion time in time-shared allocation policy. At n = 68, as the bandwidth increased from 1 Gbps to 10 Gbps, the following effects on cloudlet completion time have been noticed: (a) the time taken by cloudlets to complete the task increased, (b) At each bandwidth input (except at bandwidth = 1 Gbps & 10 Gbps), the cloudlets exhibited two type of completion time variations with one increasing and other decreasing trend.

Fig. 14 shows the effect of VM processing power on processing time. As the VM processing power increased from 250 to 2500 MIPS, the processing time decreased from 160 s to 16 s. The reason behind this result can be associated with the fact that higher VM processing power will cause faster execution of cloudlets.

## 6. Conclusion

The development of smart grid will led to generation of large amount of complex data. Inadequate existing infrastructure (network, storage and compute servers) will pose challenge for accomplishing the complete smart grid vision for some nations. On the other hand the advantages of cloud computing can help the smart grid in meeting the computing and storage demands. This paper presented the simulation model of smart grid cloud and illustrated the effect of variation of various parameters like number of VM's, VM Image size, RAM size, VM processing power, VM bandwidth, length of cloudlets on cost and cloudlets completion time. In case of time-shared allocation policy, when

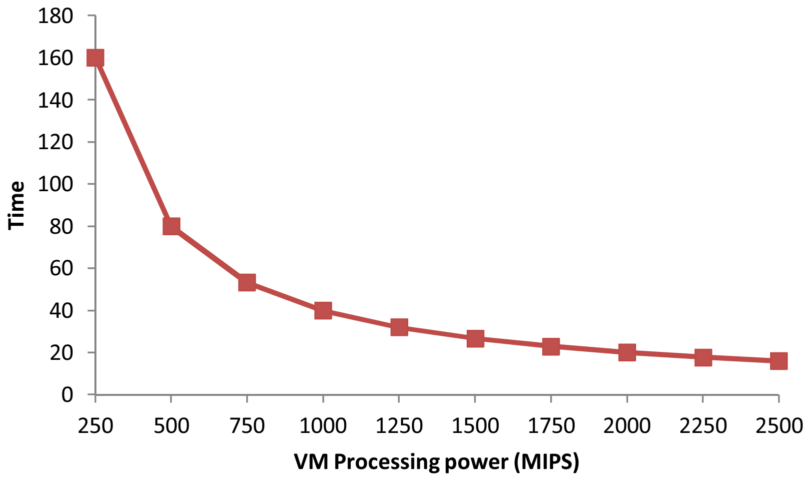


Fig. 14. VM Processing power (MIPS) vs processing time.

number of cloudlets (n) is increased from 68 to 178, the time taken by the cloudlets for task completion also increased. At n = 68, 100% of cloudlets complete their execution in time = 160 s while at n = 178, 71% of cloudlets complete their execution in time = 480.1 s. In case of space-shared allocation policy, at n = 68, 100% cloudlets complete their execution in 160 s while at n = 178, 38% of cloudlets completed their execution in 160s, another 38% of cloudlets in 320 s and rest of 24% of cloudlets completed their execution in 480 s. The number of cloudlets taking higher execution time is more in case of time-shared allocation policy as compared to space-shared allocation policy. The cost of processing increased linearly with respect to number of VMs, VM Image size and cloudlet length. The cloudlet completion time decreased with the increase of VM processing power. In space-shared allocation policy, as the VM RAM is increased from 512 to 5120 MB, the number of classes of cloudlet completion time also increased with small percentage of cloudlets completing in higher class of cloudlet completion time. While in time-shared allocation policy, the number of classes of cloudlet completion time remained low as compared to space-shared allocation policy. Furthermore, the maximum percentage of cloudlets completed their execution in higher class of cloudlet completion time. As the bandwidth increased from 1000 Mbps to 10,000 Mbps the cloudlet completion time also increased. In space-shared allocation policy, the number of classes of cloudlet completion time also increased with number of cloudlets distributed proportionally among the classes. While in time-shared allocation policy, the number of classes of cloudlet completion time remained low as compared to space-shared allocation policy. Furthermore, the maximum percentage of cloudlets completed their processing in higher class of cloudlet completion time. This analysis is beneficial for making decisions regarding hosting of smart grid applications on cloud and selection of appropriate VM allocation policy. The future work includes the development of security policies for smart grid cloud to ensure confidentiality, integrity and availability of data. Development of intrusion detection and intrusion prevention systems for smart grid cloud is also a key area to be explored.

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## References

Abdelsalam, H.A., Abdelaziz, A.Y., 2014. A brief overview of nanotechnology applications in smart power grid. Electr. Power Compon. Syst. 42 (3–4), 306–314.

Buyya, R., Ranjan, R., Calheiros, R.N., 2009. Modeling and simulation of scalable cloud computing environments and the CloudSim toolkit: challenges and opportunities. In: Proceedings of International Conference on High Performance Computing & Simulation HPCS '09, Leipzig, June, pp. 1–11, http://dx.doi.org/10.1109/HPCSIM.2009.5192685.

Buyya, R., Broberg, J., Goscinski, A., 2011. Cloud Computing Principles and Paradigms. John Wiley & Sons, New Jersey.

Dong, G., Zhang, X., Li, Y., Yang, X., Xu, K., 2012. Building smart power utilization service system by using business process and cloud computing technologies. Energy Procedia 16, 564–570, http://dx.doi.org/10.1016/j.egypro.2012.01.091.

FICCI, India Smart Grid Day, India Smart Grid. [Online]. Available: http://indiasmartgrid.org/en/Documents/Context%20of%20Smart%20Grids%20in%20India%20-%20Knowledge%20Paper%20of%20India%20Smart%20Grid%20Day%202013.pdf (accessed 26.08.13.).

Kaplan, S.M., 2009. Smart Grid. Electrical Power Transmission: Background and Policy Issues. Congressional Research Service, Rep. R40511.

Markovic, D.S., Zivkovic, D., Branovic, I., Popovic, R., Cvetkovic, D., 2013. Smart power grid and cloud computing. Renew. Sustain. Energy Rev. 24, 566–577, http://dx.doi.org/10.1016/j.rser.2013.03.068.

Mehmi, S., Verma, H.K., Sangal, A.L., 2014a. Smart grid cloud for Indian power sector. In: IEEE International Conference on Recent Advances and Innovations in Engineering ICRAIE-2014, May, Jaipur.

Mehmi, S., Verma, H.K., Sangal, A.L., 2014b. Analysis of security issues in cloud based smart grid. Sci. Emerg. Technol. Latest Trends 18 (1), 12–21.

Mehmi, S., Verma, H.K., Sangal, A.L., 2015. Analysis of cloudlet completion time during attack on smart grid cloud. Cloud Comput. 4 (4), 353–376.

Mehmi, S., Verma, H.K., Sangal, A.L., 2016a. Economic viability of cloud based smart grid in India. Grid Distrib. Comput. SERSC 9 (2), 61–72.

Mehmi, S., Verma, H.K., Sangal, A.L., 2016b. Comparative analysis of cloudlet completion time in time and space shared allocation policies during attack on smart grid cloud. Procedia Comput. Sci. 94, 435–440.

Microsoft, The Three Layers of Cloud Computing. [online]. Available: http://www.microsoft.com/india/msindia/perspective/interfaces_cloud_three_layers.aspx (accessed 30.07.13.).

Mohsenian-Rad, A., Leon-Garcia, A., 2010. Coordination of cloud computing and smart power grids. First IEEE International Conference on Smart Grid Communications (SmartGridComm), 368–372.

NIST, NIST framework and roadmap for smart grid interoperability standards, release1.0, Jan 2010 [Online]. Available: http://www.nist.gov/public_affairs/releases/upload/Smartgrid_interoperability_final.pdf (accessed 30.07.13.).

NIST, The NIST Definition of Cloud Computing. [Online]. Available: csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf (accessed 30.07.13.).

Power Grid Corporation of India, 2016. Company Overview. [Online], Available: http://www.powergridindia.com/_layouts/PowerGrid/User/ContentPage.aspx?PId=76&LangID=English (accessed 03.01.13.).

Smart Grid Vision & Roadmap for India (benchmarking with other countries)—Final Recommendations from ISGF [Online]. Available: http://indiasmartgrid.org/en/knowledgecenter/Reports/Smart%20Grid%20Roadmap%20for%20India%20from%20ISGF.pdf (accessed 30.12.12.).

Xiao, Z., Xiao, Y., 2012. Security and privacy in cloud computing. IEEE Commun. Surv. Tutor. 15 (July (2)), 843–859.

Yigit, M., Gungor, V.C., Baktir, S., 2014. Cloud computing for smart grid applications. Comput. Netw. 70, 312–329, http://dx.doi.org/10.1016/j.comnet.2014.06.007.