CloudNetSim++: A Toolkit for Data Center Simulations in OMNET++

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***Abstract*—With the availability of low cost, on demand, and pay-as-you-go model based utility computing services offered by clouds, multiple businesses consider moving their services to the cloud. Typically, the clouds comprise of geographically distributed data centers connected through a high speed network. Most of the research and development is focused on cloud services, applications, and security issues; however, very limited effort has been devoted to address energy efficiency, scalability, and high-speed inter and intra-data center communication. We present CloudNetSim++, a modeling and simulation toolkit to facilitate simulation of distributed data center architectures, energy models, and high speed data centers' communication network. The CloudNetSim++ is designed to allow researchers to incorporate their custom protocols and, applications, to analyze under realistic data center architectures with network traffic patterns. CloudNetSim++ is the first cloud computing simulator that uses real network physical characteristics to model distributed data centers. CloudNetSim++ provides a generic framework that allows users to define SLA policy, scheduling algorithms, and modules for different components of data centers without worrying about low level details with ease and minimum effort.**

Keywords—cloud computing; data center; OMNeT++; energy efficiency;

I. INTRODUCTION

Clouds are formed from a large set of one or more geographically distributed data centers. Multinational Information Technology (IT) companies, such as Google, Facebook, Amazon, and Microsoft are the pioneers in cloud computing to provide a variety of cloud-hosted services, such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) over the Internet [1]. The IT hardware, which include tens of thousands of computing servers and network infrastructure hosted in data centers consumes considerable amount of energy and requires the availability of specialized cooling mechanism to operate efficiently [2, 3]. The operational cost of each data center is notable, as it requires a significant amount of energy [4]. The overall cost of cooling equipment is around $2 to $5 million per year [5]. It is the service providers' responsibility to keep the system up and running around the clock to avoid violation of the Service Level Agreement (SLA) between the user and service providers. A major amount/portion of heat energy (over 70%) is generated through IT equipment within a data center [6]; various techniques such as Dynamic Voltage and Frequency Scaling (DVFS) and Dynamic Power Management (DPM) are adopted for energy efficiency [7, 3, 8]. Therefore, the service providers always overprovision data centers to handle peak loads. The average workload is around 30% of the entire data center's processing capacity [3]. The aforementioned implies that idle resources can transition to sleep mode unless required to handle the workload [9, 10]. However, due to the increase in the usage of cloud services, efficient use of data centers and scalability has become a critical research challenge [11]. Therefore, to support research community in investigating these challenges, we developed CloudNetSim++, a realistic network based data center communication model. It enables exploration of the energy, optimization, energy-aware scheduling, work consolidation, and scalability related issues in geographically distributed data center architectures.

This paper focuses on distributed data centers, communication models, and energy consumption. The work consolidation, energy-efficient scheduling [19] and other optimization schemes is beyond the scope of this paper. The CloudNetSim++ can simulate geographically separated data centers connected with high speed communication links. CloudNetSim++ uses real physical network characteristics for intra and inter-data centers connectivity, and makes it a unique tool compared to existing simulators.

The CloudNetSim++ is developed as an extension to OMNeT++, provides a rich GUI to simplify analysis and debugging. Another salient feature of CloudNetSim++ is that addition of data center resources, such as racks, computing servers, routers, and switches is made easy through user interface. The rest of the paper is organized as follows. The mostly used simulators are discussed in Section 2. Section 3 briefly describes the data center network architectures; energy models are defined in Section 4. The experimental setup and simulation results are discussed in Section 5. Finally, we conclude the paper by providing future research directions pertaining to the CloudNetSim++ simulator, in Section 6.

II. Related Works

This section provides a brief description of the most commonly used simulators. CloudSim [12] is the most widely known Cloud computing simulator. CloudSim is an event based simulator implemented in JAVA. CloudSim can model network components like switches, but it lacks the implementation of physical network properties. Alternatively, DartCSim+ [13] is developed as an extension of CloudSim that supports communication delays. Similarly, NetworkCloudSim [14] is proposed as an extension of CloudSim to remove the limitations and provide support for Cloud environment running different type of applications that can communicate with each other through message exchange. GreenCloud [15] is a relatively new simulator compared to CloudSim, built on top of NS2 [18]. GreenCloud was a collaborative project of University of Luxembourg and North Dakota State University. The GreenCloud simulator uses packet level communication model to simulate complex simulation models. Bilal et al. designed a data center simulator to analyze the network behavior of various data center network architectures [20, 21, 24]. However, the authors did not explore the distributed data centers. iCanCloud [16] and CloudNetSim is designed to perform Cloud simulations, it is build on the top of OMNeT++. iCanCloud allows users to measure the cost and performance of their applications running on different hardware; whereas CloudNetSim is designed to study resource management and scheduling algorithms. GreenCloud, CloudNetSim and iCanCloud are not designed to support distributed data center models.

III. The CloudNetSim++ Simulator

The goal of the cloud computing paradigm is to utilize the computing power of the data centers, which is considered as a replacement for office-based computing. However, to process large amounts of data, a significant amount of energy is required that is utilized by servers, switches, communication links, and cooling equipment. To efficiently utilize energy, several techniques are adopted, such as sleep scheduling and virtualization [22]. In CloudNetSim++, we present flexible data center models and compute detailed energy utilization of three components: (a) servers, (b) communication links, and (c) the data center infrastructure, such as router and switches.

CloudNetSim++ also introduces the concept of distributed data centers, connected with physical network, where simulation of geographically distant data centers can be carried out by connecting the core nodes of the data centers through various topologies. Heterogeneity in data center, architectures is also supported. The CloudNetSim++ is designed in a modular fashion to allow researchers to explore different aspects of data center models through diverse traffic patterns. CloudNetSim++ is the first distributed data center simulator, developed over OMNeT++ and use real physical network properties for communication. The graphical user interface of CloudNetSim++ is shown Fig. 1.

The CloudNetSim++ simulator offers a possibility to add more racks; and extend network topology by adding switches at the aggregation and core levels. One of the CloudNetSim++ objectives is to provide a platform for analyzing energy consumed by different components of data centers. In CloudNetSim++, computing servers are the processing nodes. Each server has a computing power defined in Million Instructions Per Second (MIPS). The complete model of three-tier data center is implemented; several geographically separated data centers can be connected to each other through various network topologies.

CloudNetSim++ provides a user interface to allow user to define computing servers for each rack. Every computing server is composed of multiple modules. Researchers can execute different application based on their requirements at the top module, i.e., application module. The CloudNetSim++ supports UDP, TCP, and HTTP based communication among applications. Researchers can generate different types of traffic as required. All of the features offered by the OMNeT++ and frameworks developed using OMNeT++ can be easily incorporated in CloudNetSim++. A standalone energy model called EStandardHost is incorporated within every computing server in CloudNetSim++. EStandardHost can be used and customized by researchers by inheriting the computing machine modules from EStandardHost. Similarly, energy modules of routers/switches are implemented in ERouter module and all of the routing and switching devices are inherited from this module. The CloudNetSim++ at the application layer allows user to generate traffic at constant or random intervals.

CloudNetSim++ provides simulation environment of geographically distributed data centers and each data center can be comprised of different architectures containing variable numbers of computing machines and connected with other data centers through different topologies. In CloudNetSim++, tasks are generated though user module, which are scheduled on different data centers, depending on their computing requirement and selected/customized resource allocation strategy. As stated in [15, 23], idle servers consume around 66% of energy. This energy is utilized in handling different modules of computing system, such as memory, disk, and I/O. Therefore, performing proper allocation requires a central scheduler that can allocate tasks on different computing servers and optimize energy consumption. The energy-aware scheduler is connected with core switches to distribute user tasks. The power management can be achieved with Dynamic Voltage and Frequency Scaling (DVFS) technique. In DVFS, switching power in chip decreases proportional to $V^2 * F$, where V is voltage and F is switching frequency. The frequency downshift would result in decrease in voltage, but there are certain components which are not linked with frequency, such as bus, memory, and disk. Therefore, average power consumption is stated as below:

$$P = P_C + CPU_f * f, \quad (1)$$

where P_C is power consumed by components not linked with frequency, CPU_f is CPU power consumption linked with frequency. Different architectures of data centers require different number of switches. Servers are usually arranged in racks and are connected with a Top of Rach (ToR) switch. Each ToR switch can support 1GE or 10GE speeds. To reduce the cost of data centers, usually 1GE is used. Initially, DVFS and

Adaptive Link Rate (ALR) were used for power optimization, but this could downgrade the transmission rate [7, 25].

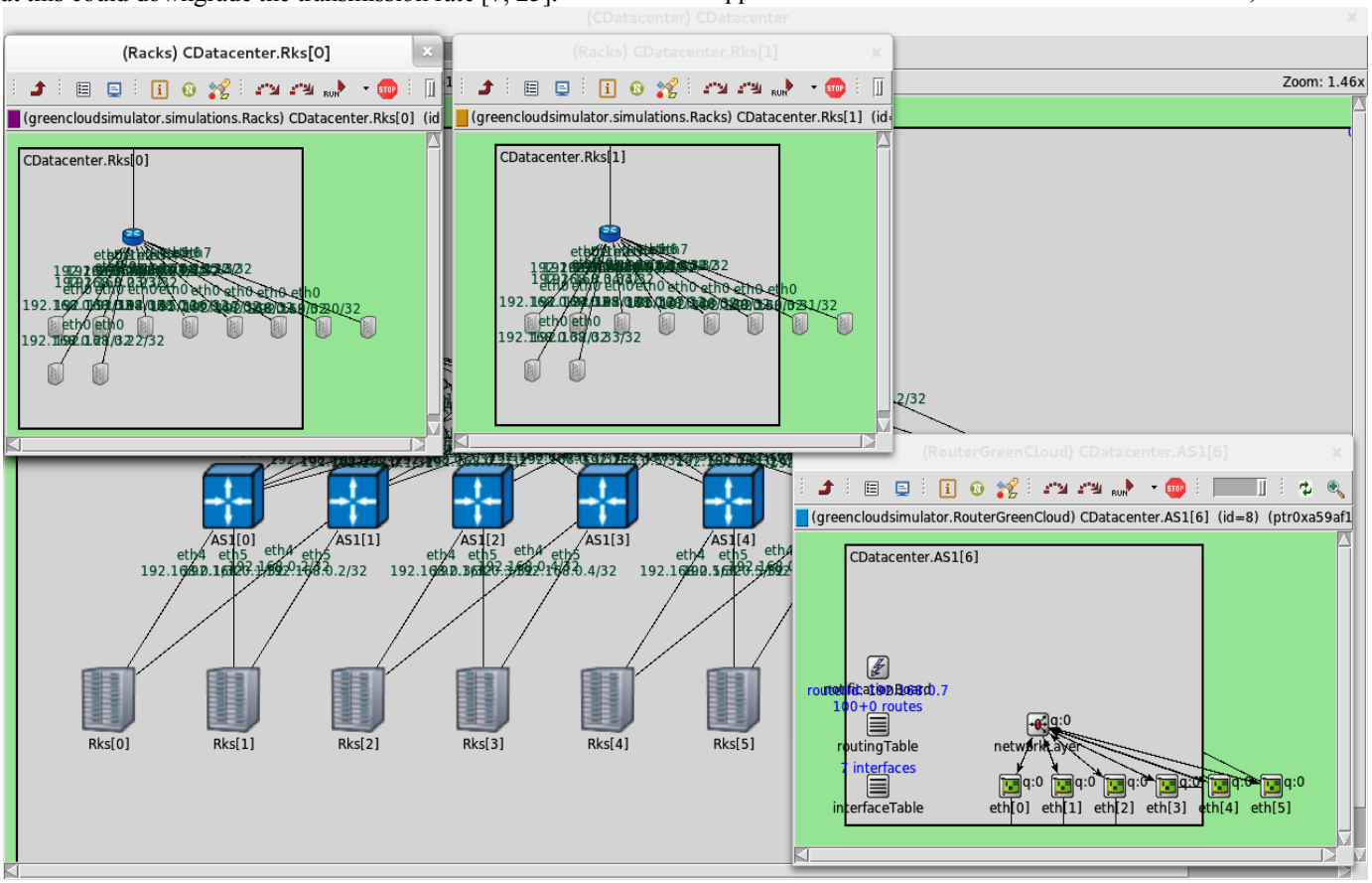

Fig. 1. CloudNetSim++ user interface.

The options for transmission rate that can be utilized within data centers are 10Mbps, 100Mbps, or 1Gbps. As stated in [17] the energy consumed by a switch can be expressed as:

$$P_{switch} = P_{chassis} + n_{linecard} \cdot P_{linecard} + \sum_{i=0}^{R} n_{port,r} \cdot P_r, \qquad (2)$$

where $P_{chassis}$ corresponds to the power consumed by switch hardware, $P_{linecard}$ is the power consumed by line cards, while P_r is a power consumed by a port operating at a rate r.

Only the last component in Eq. (2) depends on the transmission rate, whereas the rest are independent of the rate. As a result, network switch still consumes significant amount of energy even with no traffic forwarding. This can be prevented by turning off the switch or using a sleep mode technique. The CloudNetSim++ implements the energy consumption model according to Eq. (2).

In CloudNetSim++, we present a distributed data center model where data centers are located at different geographical locations; and each data center may implement a different architecture. In this paper, our focus is on distributed three-tier architecture. CloudNetSim++ provides several options to connect remotely located data centers using a variety of topologies. Currently, the mesh and star topologies are supported. As an extension of our CloudNetSim++, we would like to incorporate other data center models, such as BCube [20] and DCell [1] to introduce the concept of distributed energy-aware scheduling between dissimilar architectures.

IV. Performance Evaluation

In this section, we present a case study of energy-aware distributed data center model simulated in CloudNetSim++. We used two traffic scenarios. The first uses many-to-one node selection traffic patterns to analyze the data center model. In this scenario, the generated tasks are scheduled on a single node. The communication occurs at fixed intervals of time with a constant bit rate. This scenario is used to measure the energy consumption on a single server and related switches with high workload. The second scenario uses random node selection pattern. In this case, the generated tasks are scheduled on randomly selected nodes within a data center. Among geographically distributed data centers, tasks are scheduled through random data center selection process. To analyze the aforementioned scenarios, we used four geographically distributed data centers which are connected through mesh or star topology.

In CloudNetSim++, each node having computation power defined in MIPS. The generated tasks can be heterogeneous in terms of computational requirements. The simulation setup parameters are shown in Table 1. Average packet delay and

network throughput are calculated using equation mentioned in [24] and given below:

$$\tau_{avg} = \frac{\sum_{j=1}^{n} \tau_j}{n}, \qquad (3)$$

where τ_{avg} is the average packet delay, τ_j is the delay of packet j, n is the number of packets received. Average network throughput is calculated as:

$$S = \frac{\sum_{i=1}^{n} P_i \cdot \sigma_i}{\sum_{j=1}^{n} \tau_j}, \qquad (4)$$

where S is the network throughput, σ_i is the size of the ith packet and P_i is the ith packet received.

We measure the energy consumed by servers and switches for the many-to-one traffic scenario. Fig. 2 and Fig. 3 illustrate the energy distribution among geographically distributed data centers, and components of data centers (the energy measured among distributed data centers are based on randomly selected data center. The energy consumption can be improved by incorporating different scheduling schemes).

Table 1: Simulation setup

S.No	Simulation Parameters	
	Parameters	***Value***
1	Inter-Data Center (DC) topology	Star/Mesh
2	Intra-DC topology	three-tier
3	Inter-DC link	100-Gbps
4	Data center to data center link (Bit Error Rate)	10^{-12}
5	Core to aggregate link	10 Gbps
6	Aggregate to access link	1 Gbps
7	Access to servers link	1 Gbps
8	Core to aggregate link (BER)	10^{-12}
9	Aggregate to access link (BER)	10^{-12}
10	Access link to computing servers (BER)	10^{-5}
11	Packet size	1500 bytes
12	Core nodes	8
13	Aggregate nodes	16
14	Access nodes	256
15	Computing server	2200 - 9000

On average, computing servers consume around 71% of the total energy, whereas the remaining 29% is consumed by other components [16]. We measure the average delay and network throughput for simulation parameters described in Table 1 for: (a) many-to-one traffic scenario and (b) random traffic scenario. Fig. 4 presents the results for the delay measurements, while Fig. 5 shows the average throughput for varying number of computing servers in a single data center. In many-to-one scenario, network load on communication links may result in congestion and high delays; whereas in random simulation scenario, the traffic generated within data center is distributed more uniformly, as destination nodes are selected randomly. These two scenarios are selected for testing because of the traffic generated in both scenarios follows different routes. The observed throughput of many-to-one scenario is better than in the random scenario. We simulated the distributed data center model in CloudNetSim++ simulator by placing four data centers at distinct locations and connecting them through: **(a)** mesh topology and **(b)** star topology. The average throughput and delay are measured. Results for delay and throughput for many-to-one testing scenario are shown in Fig. 6 and Fig. 7, respectively.

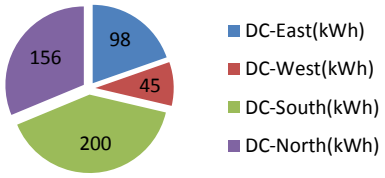

Fig. 2. Energy consumed at distributed data centers inside CloudNetSim++

The simulation results depict the behavior of distributed data centers connected through star and mesh topology under Many-to-one traffic pattern. It can be observed from Fig. 6 and Fig. 7 that the mesh topology performs better than star topology in terms of the throughput and delay.

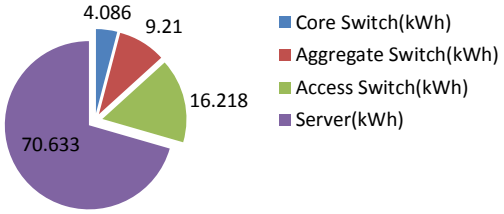

Fig. 3. Energy consumed at different components of data center (DC - East).

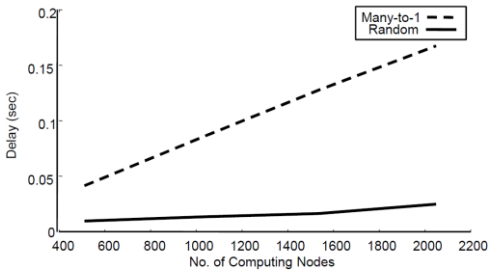

Fig. 4. Average delay for Many-to-one and Random traffic scenario

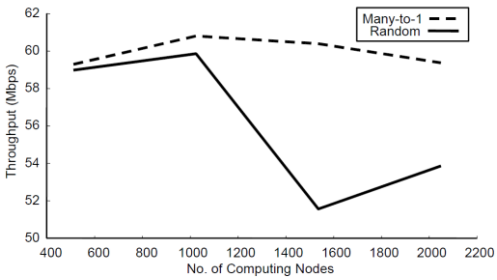

Fig. 5. Average network throughput for Many-to-one and Random traffic scenario.

As the number of nodes is increased, the throughput changes in both of the topologies. In star topology, all of the nodes are connected with central router; whereas in mesh topology each data center is connected with multiple routers. Therefore, provides many alternate paths for communication among data centers.

V. CONCULSIONS

In this paper, we presented CloudNetSim++; a simulator for distributed data centers. CloudNetSim++ provides an extensive simulation framework to assist researchers to analyze energy consumption by varying number of nodes and other parameters,

in addition to standard network performance measures like delay and throughput for various topologies. CloudNetSim++ provides a rich GUI, and communication among different nodes is achieved through packets. CloudNetSim++ is designed to study energy consumption at different components of data centers. In future, other advance data center architectures, scheduling algorithms, VM migration, and consolidation schemes will be incorporated to provide an extensive Cloud packages.

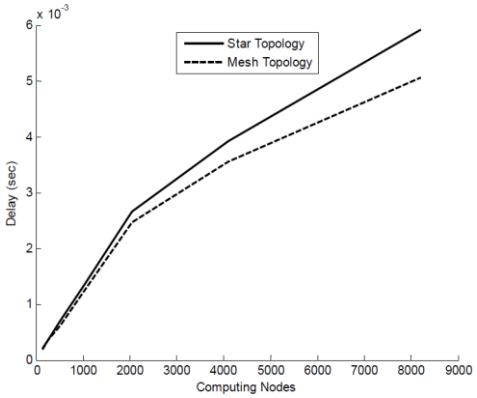

Fig. 6. Average network delay for Mesh and Star connected distributed data centers

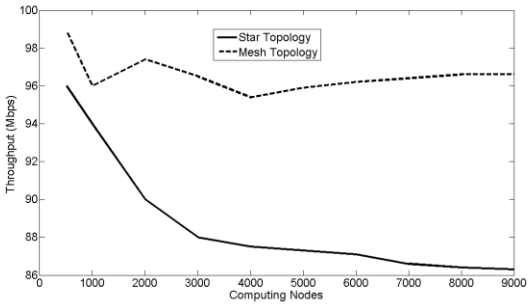

Fig. 7. Average throughput for Mesh and Star connected distributed data centers

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