Exploration of Energy-Proportional Distributed Systems

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Abstract

With the advent of Internet of Things (IoT) and the increase of the Internet Services, more and more datacenters are needed to manage the Internet traffic. Energy consumption related to these infrastructures have already reached more than 2% of the global energy consumption and it is estimated to increase in the next years. Trends such as a billion more people coming online in developing countries, IoT, driverless cars, robots, and artificial intelligence (AI) are major drivers of unrelenting growth. Our work is intended to explore new distributed architectures to deploy datacenters in order to reduce their energy consumption and reach the energy proportionality. An effort in the use of Renewable Energy Sources (RES) and Energy Storage Systems (ESS) is done in order to approach the zero-carbon emission objective. In this sense, microgrid, nanogrid and smart grid structures are analyzed in terms of stability, architecture, control, communication and energy management.

Index Terms - *Distributed Systems, Smart Grid, Cloud Computing, Multicore, Energy Management.*

1. Introduction

With the advent of Internet, people and electronic systems have the possibility to exchange information by using the network. Chat, video chat, social networks, online gaming, video conference, streaming video, Cloud computing are some of the services Internet can offer today. Moreover, Internet of Things (IoT) is another application which is taking place nowadays and permits objects to be connected to Internet in order to enhance them with smart features. All of these services generate a huge traffic of data through the network.

Trends on datacenters' power consumption. Datacenters play a key role in managing and processing these data. Indeed, companies like Facebook, Google, Amazon, already have many of these high computing and storing centers to manage users requests all over the globe. In this way, energy consumption of datacenters have already reached more than 2% of the world's electricity [1]. The Information and Communication Technology (ICT) sector predicts to use 20% of all the world's electricity by 2025 and emit up to 5.5% of all carbon emissions. That number could surge as high as 14% by 2040 as a torrent of internet-connected devices, high-resolution photos, streamed videos, emails, surveillance camera footage, cell phones, and smart TV require more compute power, greater amounts of network bandwidth, and ever-higher amounts of storage capacity. Moreover, low-efficiency of power supply and the need of cooling systems makes these centers very inefficient. It is estimated that datacenters waste more than 50% of the their total energy in power supply losses and cooling systems. Energy proportionality is reached when all the energy losses are eliminated. In this way, the overall power consumption of the system become proportional to its performance.

Motivations of the current study. Our work aims to explore new architectures allowing to increase the overall efficiency of this systems trying to reach the energy proportionality. In this sense, distributed architectures are good candidates because they reduce or eliminate the necessity of cooling systems. Moreover, distributed architectures offer other advantages like modularity, scalability, reliability etc. This permits to manage the increase of the demand, by simply adding new modules to the system. Faults would be managed by simply replacing the damaged module without compromising the Quality of Service (QoS) of the whole system which will be guaranteed by all the other modules.

On the other hand, distributed architectures find a good matching with renewable energies such as solar, wind, etc., because the distributed nature of the latter. Then, integration of Renewable Energy Sources (RES) with ICT will be considered by using micrograds and smart grids technology. In fact, by exploiting RES, the zero-carbon emission objective could be reached. Energy management policies and online optimization algorithm are also explored to increase the efficiency of the overall system. Integration of System of Chip (SoC) in these systems is foreseen to add these smart features directly on chip.

2. Distributed Systems

A distributed system is a set of independent components that appears to its users as a single coherent system or as a single system. Two examples of distributed systems are presented in this section: cloud computing infrastructure in data-domain and smart grid infrastructure in energy-domain.

Cloud computing infrastructure. A Cloud computing infrastructure consists of a set of interconnected computers, storage systems etc. which appear to the end-user like a single machine. This allows the end-user to take advantage of a powerful hardware infrastructure without buying it. In fact, these services can be rent on-demand. Of course, several software abstraction layers are needed which virtualizes resources and logically presents them to users through application program interfaces and API-enabled command-line or graphical interfaces.

Smart grid infrastructure. In the same way, a smart grid infrastructure consists of a set of interconnected energy sources, loads and Energy Storage Systems (ESS) which appear like a single, large energy bank. An energy source can connect to this energy bank to inject energy. Instead, a load can connect to this energy bank to take energy. Of course, this kind of network needs different control software layers in order to guarantee stability of the power network and QoS. In fact, stability, efficiency and maximum resource utilization are some of the challenges these systems are facing up. Distributed control algorithms, energy sharing policies, online optimization algorithms are some of the directions researchers are taking to solve these problems. All of these challenges have the common goal of creating an energy bank that can be used for the interconnection of an ever increasing set of heterogeneous sources and loads.

3. Towards an Energy-Proportional Distributed Computing

A novel approach is investigated in our work, which integrates the cloud computing technology with the smart grid technology. In this approach, a smart grid is used to feed a cloud computing infrastructure. More specifically, each server of the Cloud computing infrastructure can be fed on-demand by the smart grid as illustrated in Figure 1. This enables the integration of zero-carbon emission RES with conventional Fossile Energy Sources (FES). Moreover, intrinsic advantages of distributed systems make this architecture more reliable, scalable and efficient. The smart grid is composed by a grid-connected DC MicroGrid (DCMG) whose intelligence is given by the integration of SoCs.

DC MicroGrid. A DCMG is an electrical system that can efficiently distribute, consume and potentially create and store, Direct Current (DC) electricity to feed a wide variety of electrical devices. Several DCMG architectures have been proposed in the last decades [2]. These can be classified into six main categories: single-bus DCMG, Multi-Bus DCMG, Multi-Terminal DCMG, Ring-Bus DCMG, Ladder DCMG, Zonal DCMG. The choice of the DCMG architecture influences many factor such as the cost of the project, robustness, resiliency, controllability and hierarchy of the system, reliability, availability, resource utilization, and flexibility.

Communication and control are also important in order to have an efficient operation and guarantee for stability. Several control strategies can be applied to DCMG such as voltage and current control, load sharing, power flow control, economic dispatching, minimization of transmission losses etc. In order to obtain these objectives, centralized, decentralized and distributed control methods are investigated. Moreover, energy management policies and online optimization techniques are explored in order to increase the overall efficiency of the system and guarantee the QoS. Machine Learning-based techniques can be one of the possible directions.

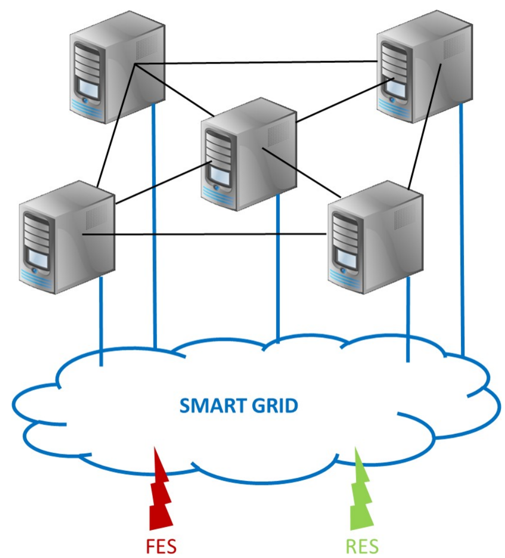

Figure 1. Proposed approach.

4. Conclusions

This work proposes an Energy-proportional Distributed Computing infrastructure to solve the problem of energy waste in datacenters. This infrastructure merges two recent technologies: Cloud Computing and Smart Grid. DCMG architectures are explored and integrated with SoC to add smart features. Distributed Control algorithms and Distributed communication techniques are investigated to better control this system in data-domain and energy-domain. Integration of RES is also considered to reach the zero-carbon emission objective. Finally, energy management policies and online optimization algorithms will be explored in order to increase the energy efficiency of the proposed system.

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