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Consideration of marginal electricity in real-time minimization of distributed data centre emissions

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A B S T R A C T

Among the innovative approaches to reduce the greenhouse gas (GHG) emissions of data centres during their use phase, cloud computing systems relying on data centres located in different regions appear promising. Cloud computing technology enables real-time load migration to a data centre in the region where the GHG emissions per *kWh* are the lowest. In this paper, we propose a novel approach to minimize GHG emissions cloud computing relying on distributed data centres. Unlike previous optimization approaches, our method considers the marginal GHG emissions caused by load migrations inside the electric grid instead of only considering the average emissions of the electric grid's prior load migrations. Results show that load migrations make it possible to minimize marginal GHG emissions of the cloud computing service. Comparison with the usual approach using average emission factors reveals its inability to truly minimize GHG emissions of distributed data centres. There is also a potential conflict between current GHG emissions accounting methods and marginal GHG emissions minimization. This conflict may prevent the minimization of GHG emissions in multi-regional systems such as cloud computing systems and other smart systems such as smart buildings and smart-grids. While techniques to model marginal electricity mixes need to be improved, it has become critical to reconcile the use of marginal and average emissions factors in minimization of and accounting for GHG emissions.

1. Introduction

Information and communication technologies (ICTs) have grown exponentially in the last decades and this rapid growth is expected to continue (Gantz and Reinsel, 2012). However, manufacture and use of ICTs are associated with large electricity and resources consumption (Lannoo et al., 2013). In 2006, ICTs were found to contribute to 2% of global anthropogenic greenhouse gas (GHG) emissions, which were equivalent to the emissions of the aviation industry for that year (The Climate Group, 2008). Because data centres are one of the three major sinks of electricity among ICT infrastructures, they also significantly contribute to ICT GHG emissions (Lannoo et al., 2013). Therefore, significant effort has been invested to curb data centre electricity demand, improve their efficiency and reduce their environmental footprint (Beloglazov et al., 2012; Doyle et al., 2013; Van Heddeghem et al., 2012).

Among the innovative approaches to reduce data centre use-phase GHG emissions is overall load management across distributed data centres (Amokrane et al., 2013; Krioukov et al., 2011; Mandal et al., 2013). In this approach, data centres are located in several regions and connected to the regional electrical grid. Load management is used to vary the power demand of the data centres in real time to maximize power consumption in regions where the GHG emissions per *kWh* are the lowest. Indeed, electricity is generated to instantly meet the regional power demand, which changes continuously during the day, depending on consumer needs. Therefore, the regional mix of power plants changes constantly, as does the related GHG emissions factor per *kWh*. Thus, there is an opportunity for distributed data centres to minimize their GHG emissions in real-time by identifying the least emitting sources of electricity.

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1.1. Problem statement

According to our knowledge, in this innovative approach, the choice of region to which the load is migrated to is related to real-time electricity generation data (in the best cases). Concretely, the electrical grid mixes several regions are checked regularly and then the load is balanced between regions where the GHG emissions are lower at a given time. This means that the changes in regional power demand caused by the load balancing are not taken into account in this approach, since the load balancing is made after the grid mix check. Consequently, the regional grid mix change (and its consequences on regional GHG emissions) directly caused by load management is also ignored. In other words, the current load balancing approach would not capture an increase in regional coal power generation caused by a rise in the load processed by a data centre in that region. Thus, there is uncertainty regarding the real GHG emissions reductions achieved (if any) with the optimization of data centre networks when using the current load balancing approach. Therefore, a method adapted to the dynamic electricity context is needed to instantly identify power plant types affected by load balancing and minimize the GHG emissions of distributed data centres.

1.2. Objectives

Thus, the objectives of this study are to:

- Highlight the need to consider marginal sources of electricity when optimizing distributed data centres using load balancing,
- Present approaches to identify marginal sources of electricity,
- Discuss issues related to multiregional optimization based on marginal electricity management and GHG emissions accounting.

A case study has been built to illustrate these objectives. In this case study the GHG emissions of a cloud computing service are minimized using load balancing between distributed data centres located in two different Canadian provinces.

2. Method

This section begins with a description of the case study used to illustrate the role of marginal electricity in a Canadian data centre network. Then, the method used to identify the marginal sources of electricity is presented. Finally, several scenarios are defined to evaluate the method's performance.

2.1. The Green Sustainable Telco Cloud

The case study involves the Green Sustainable Telco Cloud (GSTC) that is defined as a cloud computing service based on an efficient, optimized and environmentally-friendly distributed data centre network. Several optimization criteria, such as service quality, GHG emissions and operating costs, are considered. However, this paper focuses only on the environmental criteria to fully illustrate the role of the marginal sources of electricity in GHG emissions. The GSTC is currently under development, and the case study presented here is therefore based on a scenario rather than real results. It was deliberately simplified and is more conceptual than practical. Thus, it does not present accurate and complete GHG emissions results.

In this case study, two virtualized data centres are located in the Canadian provinces of Ontario and Alberta and form a cloud computing system that provides online services. These provinces were chosen because detailed, historic and real-time electricity generation data are available from public sources (AESO, 2013; IESO, 2013). It is assumed that the two data centres are similar and connected to the regional grids and that only one handles the cloud computing service at a time. In addition, the cloud power demand varies over time on a daily basis, depending on user requests, as presented in Fig. 1. It is also assumed that data transmission by all users towards the data centres consumes the same amount of electricity, regardless of the location of the data centre hosting the cloud.

It is considered that one load migration between the two data centres could be made every hour. Assuming that the GSTC provides an online service that host a negligible amount of user data, the load migrations should not cause significant additional data traffic. Consequently, the electricity consumption due to such data traffic has been neglected. Concretely, the GSTC service could consist of online file processing, such as picture or video editing or mathematical computing.

2.1.1. Definition of marginal electricity

Electrical grid networks are balanced between producers and consumers. In practice, the electrical grid operator must keep the power generation capacity close to the power demand. Since the power demand changes over time due to consumer behaviours, producers must constantly adapt their power generation capacity. Adapting power generation capacity in real time depends on various criteria such as the flexibility of the power generation technologies, the power plants' operating costs, the electrical grid constraints and the electrical grid operator schedules. By definition, a power plant that adapts its power generation capacity in response to a change in power demand is a marginal source of electricity. The marginal electricity is the electricity generated by all the marginal sources. Several observations in the electricity sector show that, for a very small variation in power demand, there is only one marginal technology (Nielsen et al., 2011; Sensfuβ et al., 2008; Tveten et al., 2013). However, this technology may change over time, and more than one technology may be affected when the demand variation increases (Mathiesen et al., 2009; Rogers et al., 2013b). Moreover, since the marginal sources of electricity are selected among a pool of potential marginal sources of electricity, there is uncertainty in the prediction of the marginal sources of electricity. To overcome this problem, past data were used in this study to retrospectively identify the marginal sources of electricity. These data are retrieved from the Canadian electric utilities (AESO, 2013; IESO, 2013).

2.1.2. Assumption on GSTC power demand

To simplify electricity generation modeling, the cloud power demand in Ontario and Alberta is considered to be entirely met by marginal sources of electricity. A different and perhaps more

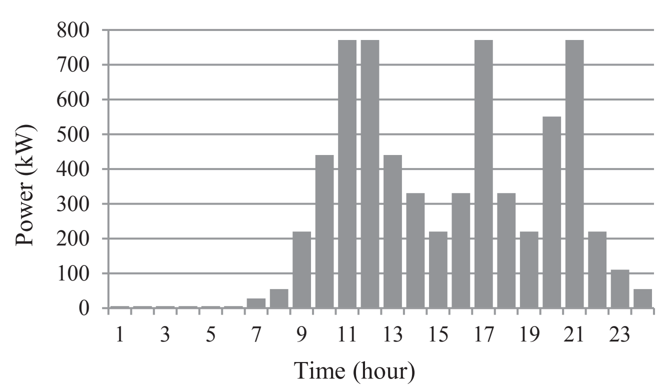

Fig. 1. Hourly cloud power requirement.

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