Abstract （論 文 の 内 容 の 要 旨）

論文題目　Reducing Energy Consumption of Data Centers by Improving Virtual Machine Live Migration（仮想マシンライブマイグレーションの高効率化によるデータセンタ消費電力の削減）

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Cloud computing has become a common computing paradigm both for individual and enterprise uses. As the use of cloud computing emerges, data centers for hosting clouds are becoming huge. In particular, large amount of energy consumption by data centers is one of the biggest issues in this cloud age. Energy consumption of data centers have been evolving by more than 10% per year, and it counts for non-negligible part of the whole energy consumption of countries such as the US.

In order to reduce energy consumption of data centers, the goal of this thesis is to achieve green data centers with aggressive VM relocation at runtime using efficient live migration. There are two problems that must be tackled to achieve this goal:
1. Live migration efficiency is not fully optimized yet. More concretely, a part of memory transfer mechanism of live migration costs much despite of the efforts by many live migration optimization researches.
2. Integrated evaluation of aggressive VM relocation at runtime and live migration is missing in the research field. This lack causes a problem that actual energy saving given by aggressive VM relocation cannot be easily estimated without using real

implementation and real servers.

To tackle these problems, this thesis has three contributions for reducing energy consumption of data centers by improving efficiency of live migration.

1. First, this thesis discusses the requirements and the technical challenge toward goal that are missing in existing studies. They include efficient live migration and integrated evaluation of live migration and aggressive VM relocation and this thesis tackles both of them.
2. Second, this thesis proposes efficient live migration methods with two novel ideas: memory reusing and parallel transfer of page cache.

The first idea is based on an observation that in an aggressive VM relocation system VMs migrate many times among a certain set of PMs such as ones in the same rack. In this situation, VMs can migrate "back" to a host on which it was executed before. MiyakoDori, the proposed system, leverages this fact for efficient live migration by caching the memory image of the target VM on a migration on the source PM, and reuse the memory image when the VM migrates back in the future.

The latter idea is based on an observation that IO-intensive VMs have large amount of page cache (also known as file cache or file buffer) in the memory. In addition, modern data centers are equipped with a dedicated storage area network (SAN) along with a general purpose network (GPN). Page cache teleportation, the proposed system, utilizes the SAN and the GPN in parallel for efficient live migration of IO-intensive VMs by transferring page cache from storage PMs to the destination PM of a migration (instead of transferring it from the source PM) via the SAN.

3. Third, this thesis evaluates MiyakoDori and Page cache teleportation in integrated simulations with aggressive VM relocation algorithms. Although there are many existing researches on live migration and VM relocation, they are done separately and how much actual energy an efficient migration method can save is still not revealed. As a result of the simulation, this thesis figures out that our methods can reduce energy consumption of data centers up to a few percent, which is equivalent with a large amount of electricity usage and energy cost because the whole data center energy consumption is extremely huge.