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Efficient Operation and Management Scheme of Micro Data Centers for Realization of Edge Computing

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에지 컴퓨팅의 실현을 위한 마이크로 데이터센터의 효율적인 운영 및 관리 기법

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Abstract As 5G mobile communication services are provided, efforts are being made to provide various services to users with ultra-low latency. This raises interest in edge computing, which can provide high performance computing services near users instead of cloud computing at the network core. This paper presents an efficient operation and management scheme of a micro data center, which is an essential equipment for realizing edge computing. First, we present the functional structure and deployment plan of edge computing. Next, we present the requirements for the micro data centers for edge computing and the operation and management scheme accordingly. Finally, in order to efficiently manage resources in the micro data centers, we present resource management items to be collected and monitored, and propose a performance indicator to measure the energy efficiency.

Key Words : Micro data center, Energy efficiency, Edge computing, Operation and management, Performance indicator

요 약 5G 이동 통신 서비스가 제공됨에 따라 다양한 서비스를 초저지연으로 사용자에게 제공하려는 노력이 진행되고 있다. 이는 네트워크 코어에서 클라우드 컴퓨팅을 제공하는 대신에 사용자 인근에서 고성능 컴퓨팅 서비스를 제공하는 에지 컴퓨팅에 대한 관심을 불러 일으키고 있다. 본 논문은 에지 컴퓨팅의 실현을 위한 필수 장비인 마이크로 데이터센터의 운영 및 관리 방안을 제시한다. 먼저, 에지 컴퓨팅의 기능 구조와 배치 방안을 제시한다. 다음으로 에지 컴퓨팅을 위한 마이크로 데이터센터의 요구사항과 이에 따른 운영 및 관리 방안을 제시한다. 마지막으로 마이크로 데이터센터의 자원을 효율적으로 관리하기 위해서 수집 및 감시해야 하는 자원 관리 아이템을 제시하고, 에너지 효율을 측정할 수 있는 성능 지표를 제안한다.

주제어 : 마이크로 데이터센터, 에너지 효율, 에지 컴퓨팅, 운영 및 관리, 성능 지표

1. Introduction

Recently, efforts are being made to provide users with various services such as autonomous vehicles, augmented reality, healthcare, video analytics, mobile big data, and blockchain in any network environment with low latency[1]. In order to provide such intelligent services in user terminals, artificial intelligence technology is being actively used, so higher computing power is required. Until now, tasks that are difficult to handle in user terminals due to lack of computing power have been processed with help of cloud computing in network core.

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However, since the cloud computing is far from the user terminal, excessive transmission delay is inevitably caused. It also consumes network bandwidth between the user terminal and the cloud computing server. Due to these shortcomings, edge computing technology that provides computing power at the edge of the network is attracting attention[1-4].

Edge computing provides computing resources required by user terminals at the edge of the network closer to the user, rather than at the data center located at the network core. Regarding edge computing, there are fog computing proposed by CISCO[5], Cloudlet proposed by Carnegie Mellon University[6], and MEC standardized by ETSI[7]. While ETSI initially used the term Mobile Edge Computing, it currently uses the term Multi-access Edge Computing (MEC) for the purpose of providing edge computing on various networks such as WiFi and LTE as well as 5G[8]. Although various terms are used, the purpose of providing a computing service with ultra-low latency close to user terminals can be seen as the same.

Many studies have been conducted on the configuration and management of data centers to provide cloud computing services. In particular, in order to reduce the power consumption of the data center, many studies have been conducted on the optimal location, building energy management, power and cooling equipment, integrated operation of servers through virtualization, and energy management system[9-11]. However, edge computing is simply considered to use servers in application cases, and there has not been much discussion on how to realize it. Depending on the service provider the edge computing equipment can be simply configured and operated by computing servers, or in the form of a micro data center equipped with servers, network and storage devices, cooling devices, and power supply devices in a rack. Depending on the use of edge computing, its location may be indoor or outdoor, or may be a general office space, a computer room, or a communication room.

In this paper, we present the functional requirements and resource efficient management methods that micro data centers should have in various environments to realize edge computing. The organization of this paper is as follows. Chapter 2 describes the technical overview and functional architecture of edge computing. Chapter 3 presents the requirements of micro data centers required to provide edge computing services. Chapter 4 presents the technologies of micro data centers for the realization of edge computing in energy and operational efficient aspect. Chapter 5 proposes an operational management method for micro data centers for energy efficiency. Based on the managed data in computing resources and energy resources, we propose a performance indicator for energy efficiency in micro data centers.

2. Edge Computing

2.1 Edge computing technology

Emerging services such as autonomous vehicles, artificial intelligence, and augmented reality require high-performnace computing power and ultra-low latency. Cloud computing has high-performance computing resources, but it is far from user terminals that require services, which inevitably causes transmission delay. This led to the emergence of edge computing that could provide computing resources at the edge of the network closer to the users[12]. By offloading tasks from the user terminal to edge computing, it is possible to use high-performance computing resources as well as to extend the battery life of the user terminal.

The advantages provided by edge computing are as follows[1,12]. Since computing resources are provided closer to the user, transmission delay can be reduced and the service provisioning time can be shortened. It does not use cloud computing in the network core, so it does not consume network bandwidth in the core. It is easy to use location-based services or network context information because computing services are provided at the base station or on premise where the user is located. However, there may be a lack of usable computing resources than cloud computing, so offloading to nearby edge computing or cloud computing in the core may be necessary[13].

2.2 Edge computing architecture

Fig. 1 shows the framework of MEC[7]. Edge computing allows MEC applications to run as software on a virtualized infrastructure. To this end, the framework of edge computing is largely composed of the multi-access network level, the MEC host level, and the MEC system level. The MEC host, which implements the core of MEC, includes a virtualization infrastructure and MEC platform that provides computing, storage space, and network resources necessary to run MEC applications. The MEC platform is a set of core functions required to run MEC applications on a specific virtual infrastructure, and provides MEC services through it. MEC applications are instantiated on the MEC host's virtual infrastructure according to a request or configuration verified by MEC management.

The management function of the MEC consists of the MEC system level management (SLM) and the MEC host level management (HLM). The SLM includes a multi-access edge orchestrator with a complete MEC system overview as a key element. The MEC HLM includes the MEC Platform Manager and the Virtual Infrastructure Manager. It is responsible for managing MEC-specific functions of a specific MEC host and applications running on it.

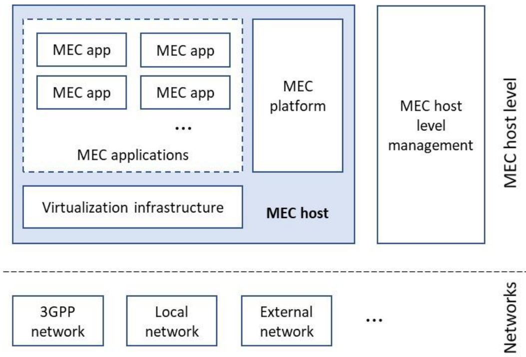

Fig. 1. Functional block diagram of MEC[7]

2.3 Location of edge computing

Edge computing aims to provide the computing resources required by a user terminal near the user's location, but the location of an actual edge computing equipment may vary depending on service providers. Depending on the deployment location, there are many restrictions on the operation and management of the micro data center, including service quality such as delay, energy consumption, network bandwidth consumption, and rental fee. Fig. 2 shows examples in which micro data centers for edge computing can be located[1,12].

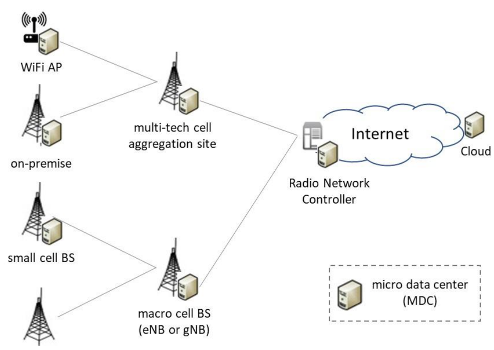

Fig. 2. Location of micro data centers for realization of edge computing

The closest location to users is to deploy edge servers to WiFi APs in homes or public places. Micro data centers can be deployed in corporate premises such as enterprises or smart factories to provide their own edge computing services. In addition to the gateway to the Internet, a central edge server can be deployed. In the case of mobile network operators, micro data centers can be deployed in base stations. Depending on the coverage of the base station, it is possible to provide edge computing services in smaller units by placing it in a small cell of about 1 km or by placing it in a femtocell or picocell in a building. It is also possible to deploy micro data centers in base stations (eNodeB, gNodeB) that cover macro cells in a range of several kilometers. By arranging a micro data center in a radio network control station (RNC), it is possible to provide edge computing services from multiple cells. These options may depend on the service strategy provided by the edge computing provider.

3. Considerations on Micro Data Center for Edge Computing

Compared to traditional data centers, micro data centers for edge computing should be viewed differently in the following aspects. First, it is the deployment location of the micro data center. The micro data center can be located in a general office, a communication room, or a Radio Network Controller (RNC) (see Section 2.3). It can be located inside the building or it can be placed outside the building. That is, it can be located in a non-dedicated space for the data center. There is a requirement for noise and vibration generated by servers, especially in a commercial building. In order to supply stable power, an intelligent power distribution device and an uninterruptible power supply (UPS) are required. The capacity of the UPS must be calculated to continuously supply power to servers until it is replaced with an alternative power source in the event of a power outage. When a micro data center is located in a general building supplied by commercial power, it is necessary to ensure that sufficient power is supplied for the operation of the micro data center and the building. It is recommended to separate the electrical power distribution for the micro data center and the office. Since air conditioning equipment for thermal cooling of servers is not provided in general office spaces, an air conditioning system should be equipped with a micro data center. A management system (or software) for the data center is necessary to manage computing resources and measure energy efficiency. Micro data centers deployed outdoors require strong physical security devices to protect against external intrusion. Table 1 summarizes the requirements for micro data centers for edge computing.

Table 1. Requirements for micro data center for edge computing

category	requirements
power supply	The power supply should be configured in consideration of the maximum power that can be consumed by the servers, storage, network equipment, cooling systems, and other security and operation equipment constituting the micro data center. It is recommended to separate electrical power distribution between the data center and the office.
redundancy	Possible failures include server failure(including component failure), storage and network equipment failure, cooling system failure, and power supply failure. Backup server can be used in racks to protect against server failures, or servers operated by other micro data centers can be used as backups using offloading. UPS should be fitted to prepare power outages. The capacity of UPS is determined by considering the time required to replace the unit.
virtualization	Since the main characteristic of edge computing technology is to process the computing of the user terminal instead, all computing resources in the micro data center should be provided as virtualization. It is required to provide virtual resources through virtual machine or container technology, network function virtualization, and software-defined networking.

(Continued)

Table 1. Requirements for micro data center for edge computing

category	requirements
computing capacity planning	It is necessary to expand the capacity of computing resources as the computing and service demands from users increase. It is possible to expand from server units to rack units. In the case of expansion of rack units, the power capacity of the building in which it is located should also be considered. Prior to physical expansion, computing offloading to a nearby micro data center or a central cloud data center should be preceded.
operation & mgmt. system	A management system is needed to monitor environmental condition such temperature and humidity, and the operational status of computing resources and power consumption in order to optimize the operating condition. The management system can be operated by itself in a micro data center, or it can be managed remotely in a central management system.
noise & vibration	If a micro data center is located in a general office (indoor), it is recommended that noise be less than 50 dB(A) and vibration be less than 50 dB(V), and noise be less than 60 dB(A) and vibration be less than 70 dB(V) if placed outdoors. It is necessary to introduce an enclosed rack enclosure for noise and vibration reduction.
physical security	When a micro data center is placed indoors or outdoors in a general building rather than a dedicated place in a data center, it is easily accessible to the general public, requiring stronger physical security and access-limiting technologies.

4. Operation Methods of Micro Data Center for Edge Computing

4.1 Redundancy policy against system failure

Failures that can occur in micro data centers can be largely divided into internal and external factors. External factors can be caused by a failure of commercial power or an external intruder. In order to prepare for the failure of the commercial power supply, the power supply needs to be redundant[14], but this is not a consideration at the micro data center level. As an internal factor, failure of the server device, storage devices, networking devices and other management equipment can be considered. In order to prepare for the failures, it is necessary to duplicate core devices such as servers. The degree of redundancy depends on the importance of the service provided. If a micro data center is composed of multiple racks, it is possible to consider redundancy in units of racks.

The availability improvement that can be obtained through redundancy of the devices can be calculated as follows. If one server is operated as a backup device for N servers, it can be called N:1 redundancy. In this case, the probability of a failure occurring in k servers at the same time can be calculated as follows with the M/M/1/N+1/N+1 queuing system[15].

$$P_k = \frac{(N+1)!}{(N-K+1)!}\left(\frac{\lambda}{\mu}\right)^k P_0 \quad (1)$$

where,

$$P_0 = \left[1 + \sum_{k=1}^{N+1} \frac{(N+1)!}{(N-K+1)!}\left(\frac{\lambda}{\mu}\right)^k\right]^{-1} \quad (2)$$

λ is the average failure rate, μ is the average failure recovery rate, and k has a value between 1 and N+1. The availability of servers in a micro data center is calculated as the sum of all servers running (P0) or when one of the N+1 servers fails (P1).

4.2 Cooling policy

According to the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the recommended and permitted temperatures for IT equipment are disclosed as 18-27 °C and 15-32 °C, respectively[16]. There is a need for a cooling system that can effectively discharge heat generated by servers placed in an enclosed space of a micro data center and operate at an appropriate temperature[17]. Various types of cooling systems can be used depending on the load of the servers and the location where the data center is located. If the server load is less than 400 W, a separate cooling system is not required and heat can be conducted through the rack surface. If the load is 400-700 W, a passive ventilation method that allows heat to flow through the vents to the cold air can be applied. If the load is in the 700-2,000 W level, a fan must be installed in the vent to dissipate heat. Blanking panels must be used to remove empty space in order to effectively dissipate heat inside the rack. If there is an empty space inside the rack, the heat emitted from the server does not drain into the vent, but stays insides the rack, preventing the air flow. If the total load of the server is 2,000 kW or more, it is desirable to install a dedicated cooling system. If the micro data center is located in a general office, cooling and ventilation systems must be integrated inside the rack enclosure to minimize vibration and noise.

4.3 Power supply policy considering server configuration

The power supplied to the micro data center must be sufficiently up to the level of maximum power consumed by servers, storage, network equipment and other management system mounted in the rack. If 1 U servers with a maximum power consumption of 500 W are fully mounted in a typical 42 U rack, the power consumed by the rack will exceed 20 kW. However, the actually required power varies depending on the number of servers mounted in the rack and the utilization of servers. According to N. Rasmussen[18], most of the power consumption per rack remains below 6 kW. Since micro data centers for edge computing are likely to be deployed in general business buildings rather than in dedicated buildings like data centers, the power capacity of the micro data center is calculated by considering the amount of commercial power that can be supplied. Consequently, the server size should be estimated based on the power supply planning.

Considering the amount of power supplied, the server can be configured in the micro data center as follows[18]. When 1 kW power is supplied, a micro data center can be operated in a general offices with a small number of servers. In case of a general rack configuration, which consumes 2-5 kW power, a separate power supply plan should be established. According to the request of a service provider, a micro data center, which consumes 7 kW power or more, can be configured with a separate power supply plan. The branch circuit for overcurrent protection between the power distribution device and the rack must be configured according to the amount of power.

4.4 Server virtualization

Like cloud computing, edge computing uses virtualization technology to efficiently use physical resources. The hypervisor-based server virtualization technology is implemented on the host operating system of the physical server. Several guest operating systems are run on the hypervisor to operate as separate virtual machines. The virtual machine has an independent operating system and provides users with virtual hardware devices and drivers that are independent of the underlying system. However, the virtual machine image is large and overhead occurs in system operation[2].

In edge computing, which has insufficient physical computing resources compared to cloud computing, it is necessary to apply a lighter and more flexible virtualization technology. Container-based virtualization technology is provided on the operating system and provides an environment for implementing specific applications or services. The container divides and uses the resources of the physical server, and can create an independent user space instance of a smaller size than a virtual machine. In particular, containers can be instantiated faster than virtual machines, making them more suitable for supporting user mobility[2].

4.5 Physical security

If a micro data center is located outdoors or in a general office, not in a dedicated space, physical security is required because the general public can access it as well as the administrator. In particular, when it is placed outdoors, the server or rack enclosure must be packaged in an integrated box form to prevent outsiders from accessing the computing device. The packaging material uses high-strength metal that cannot be disassembled with an external physical device such as a drill or hammer. EN 1627 WK4[1], a European standard for anti-theft classes for doors and shutters, etc., provides a criterion that it takes more than 10 min for an experienced intruder to break into it using a variety of tools. Security cameras are installed outside the micro data center to monitor the access and intrusion of outsiders.

5. Resource Efficient Management for Micro Data Center

5.1 Resource efficient management scheme of micro data center

The management of micro data centers can be conducted in the aspect of computing resources and energy consumption. IT-related resources such as servers, storages, and networks should be managed in order to immediately provide computing resources to users who require edge computing services. Server virtualization or container technology can be applied for efficient management of physical server resources. For this purpose, the utilizations of server CPU and memory, and storage are monitored. If the resources of the micro data center are insufficient to provide the computing resources that users request, they can offload the computing to a nearby micro data center or to a cloud computing. The managed data and computing resource data that the micro data center should manage and monitor are presented in Table 2.

Energy resource management and power saving in micro data centers are also an important management issue. So, it is necessary to periodically collect power consumed by various equipment in the micro data center. It is very important to effectively remove the heat generated by the servers. This is for the stable operation of the servers as well as power saving of the cooling system. Therefore, it is necessary to collect temperature data in the data center and operate the cooling system energy efficiently. Table 2 shows the data to be collected for energy resource management. These can be used to evaluate the energy efficiency of the micro data center.

The management system can be built for on-site management or for remote management. The on-site management system can be accessed by a manager on the spot to monitor management information. If a manager is in a remote location, the micro data center can be operated and managed by remote access through the Internet. If an on-site management system is not established, the raw data for management shown in Table 2 is periodically transmitted to the remote management system. The remote management system presents the operation information to the manager comprehensively. Edge computing service providers can provide computing resources to users based on the management information from the management system.

1) http://www.env1627.co.uk/

Table 2. Resource items for managing micro data centers

Equipment	Managed data	Computing resource monitoring data	Energy resource monitoring data
server	location, years, spec.(CPU, memory, disks, etc)	physical/virtual service CPU, memory, disk, I/O utilization	power consumption, temperature
storage	location, years, spec.(storage capacity)	storage utilization	power consumption, temperature
network	location, years, spec.(bandwidth, ports, protocols, etc), IP address, cable	port utilization/traffic, cable management information	power consumption
rack	rack ID(incl. location), server/storate/network configuration		slots/ports used information, power consumption, temperature
service	service list service periods, used resources, users, etc)	resource utilization per service	
power supply	power system capacity (PDU, UPS)		power consumption(input/output)
cooling systems	cooling capacity		power consumption
etc	security systems (camera, etc)		power consumption

5.2 Performance indicator for energy efficiency of micro data center

The Power Usage Effectiveness (PUE) is widely used as an indicator for evaluating the energy efficiency of a typical data center[19]. PUE is the ratio of total power consumed in the data center to the power consumed by IT equipment, and shows how much additional power is required to provide IT services. However, micro data centers may not have a backup power supply or cooling system to the similar level of the typical data center, so it is not proper to use this indicator as it is. While ETSI provides energy efficiency indicators for edge computing, it provides indicators that apply to mobile networks rather than to micro data centers (ie, power consumption versus traffic volume)[20]. Therefore, this paper proposes an energy efficiency indicator using the relationship between the power consumed in the micro data center and the utilization of the server.

First, an energy efficiency indicator that can be applied to a micro data center configuring only of servers without a backup power supply or cooling system can be used as follows.

$$\sum_{i=1}^{N}\frac{U_i}{P_i},\ where\ U_i=\sum_{j=1}^{M}U_{ij} \quad (3)$$

(P_i : the power consumed by server i, U_i: CPU utilization rate of server i, U_{ij}: CPU utilization of virtual machine j in server i)

It is desirable that the utilization rate of the server is higher and the power consumption of the server is lower. That is, higher value of Eq. (3) implies higher energy efficiency. For this purpose, it is recommended to use server virtualization technology to migrate virtual machines that operate on low utilization servers and to integrate them on a small number of servers.[21].

According to A. Beloglazov et al.[21], the power consumption of the server increases linearly according to the utilization rate of the CPU as follows.

$$P(u)=kP_{\max}+(1-k)P_{\max}u \quad (4)$$

(P_{max}: the maximum power consumed at the server utilization 100%, k: the fraction of power consumed by the idle server, u: the CPU utilization of server)

As shown in Eq. (4), the power consumption of the idle server has a great influence on Eq. (3). Fig. 3 shows how energy efficiency improves according to the server utilization rate for the case where the power consumption of the idle server is 10% and 30%, respectively2).

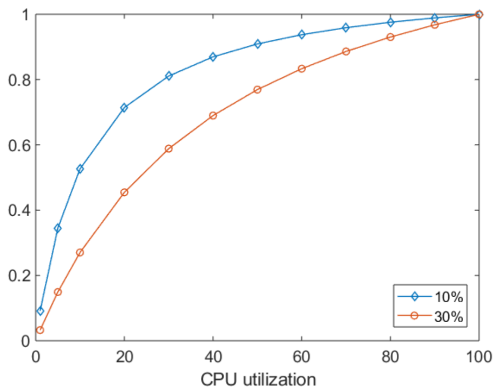

Fig. 3. Energy efficiency indicator for CPU utilization

Next, we propose an energy efficiency indicator that can be applied to a micro data center equipped with a backup power supply and cooling system. As can be seen in general data centers, the power consumed by backup power supplies such as UPS, cooling system, security and management devices used for stable operation of IT equipment is quite large. Reflecting this, the following equation can be used to evaluate the energy efficiency of the micro data center.

$$\frac{\sum_{i=1}^{N} U_i}{PUE} \qquad (5)$$

It is desirable to consume low power with high utilization of computing resources in micro data centers, the higher the value of Eq. (5), the higher the energy efficiency

6. Conclusion

This paper studied resource efficient management scheme of micro data centers for realizing edge computing. This paper presented efficient operation schemes in the aspect of redundancy, cooling system, power supply, IT equipment, physical security, vibration and noises in consideration of the service applications and location of micro data centers. For the resource efficient management of micro data centers, this paper presented the managed items on computing resources and energy resources. Based on the resource management items, this paper proposed performance indicators to evaluate the energy efficiency of the micro data center. The proposed indicator considers not only energy efficiency of the data center but also server utilization efficiency. It is expected that the presented management scheme of micro data centers can be used as a management guideline for not only edge computing service providers but also micro data center manufacturers.

2) For simplicity, the maximum power consumed by a server is assumed to be 100.

REFERENCES

[1] N. Abbas, Y. Zhang, A. Taherkordi & T. Skeie. (2017). Mobile edge computing: A survey. *IEEE Internet of Things Journal, 5(1),* 450-465.
DOI : 10.1109/JIOT.2017.2750180

[2] T. Taleb, K. Samdanis, B. Mada, H. Flinck, S. Dutta & D. Sabella. (2017). On multi-access edge computing: A survey of the emerging 5G network edge cloud architecture and orchestration. *IEEE Communications Surveys & Tutorials, 19(3),* 1657-1681.
DOI : 10.1109/COMST.2017.2705720

[3] W. Yu, F. Liang, X. He, W. G. Hatcher, C. Lu, J. Lin & X. Yang. (2017). A survey on the edge computing for the Internet of Things. *IEEE access, 6,* 6900-6919.
DOI : 10.1109/ACCESS.2017.2778504

[4] J. Choi. (2019). A study on the application of blockchain to the edge computing-based Internet of Things. *Journal of Digital Convergence, 17(12),* 219-228.
DOI : 10.14400/JDC.2019.17.12.219

[5] F. Bonomi, R. Milito, J. Zhu & S. Addepalli. (2012, August). Fog computing and its role in the internet of things. In *Proceedings of the first edition of the MCC workshop on Mobile cloud computing* (pp. 13-16).
DOI : 10.1145/2342509.2342513

[6] M. Satyanarayanan, P. Bahl, R. Caceres &N. Davies. (2009). The case for vm-based cloudlets in mobile computing. *IEEE pervasive Computing, 8(4),* 14-23.
DOI: 10.1109/MPRV.2009.64

[7] ETSI. (2019). *Multi-access Edge Computing (MEC); Framework and Reference Architecture*, ETSI GS MEC 003 V2.1.1.

[8] ETSI. (2019). *Multi-access Edge Computing (MEC); Terminology*, ETSI GS MEC 001 V2.1.1, 2019.

[9] ITU-T. (2014). *Best practices for green data centres*, ITU-T L.1300.

[10] J. Choi. (2014). Evaluation Framework for Energy Efficiency of a Cloud Data Center. *The Journal of Korean Institute of Next Generation Computing, 10(4),* 66-76.

[11] J. Choi. (2017). A Study on the Framework of an Energy-Saving Management System for Green Data Centers. *The Journal of Korean Institute of Next Generation Computing, 13(5),* 71-79.

[12] M. Patel et al. (2014). *Mobile-edge computing—Introductory technical white paper.* White Paper, ETSI, Sophia Antipolis, France (Online). https://portal.etsi.org/portals/0/tbpages/mec/docs/mobile-edge_

[13] Y. Mao, C. You, J. Zhang, K. Huang & K. B. Letaief. (2017). A survey on mobile edge computing: The communication perspective. *IEEE Communications Surveys & Tutorials, 19(4),* 2322-2358.
DOI : 10.1109/COMST.2017.2745201

[14] J. Y. Choi. (2013). Reliability Modeling of Direct Current Power Feeding Systems for Green Data Center. *Journal of Electrical Engineering & Technology, 8(4),* 704-711.
DOI : 10.5370/JEET.2013.8.4.704

[15] L. Kleinrock, (1975). *Queueing systems, vol. 1: theory.* Wiley & Sons.

[16] ASHRAE TC 9.9 (2011) *Thermal guidelines for data processing environments—expanded data center classes and usage guidance.*1

[17] V. Avelar, (2015). *Practical Options for Deploying Small Server Rooms and Micro Data Centers*, WhitePaper 174, Schneider Electric.

[18] N. Rasmussen, (2015). *Rack Powering Options for High Density*, Whitepaper 29, Schneider Electric.

[19] ISO/IEC 30134-2:2016, (2016). *Information technology - Data centres - Key performance indicators — Part 2: Power usage effectiveness (PUE).*

[20] ETSI. (2017). *Mobile Edge Computing; Market Acceleration; MEC Metrics Best Practices and Guidelines*, ETSI GS MEC-IEG 006 V1.1.1.

[21] A. Beloglazov, J. Abawajy & R. Buyya. (2012). Energy-aware resource allocation heuristics for efficient management of data centers for cloud computing. *Future generation computer systems, 28(5),* 755-768.
DOI : 10.1016/j.future.2011.04.017

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