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An IoT-Based Cloud-Fog Computing Platform for Creative Service Process

Tse-Chuan Hsu*
Centre for Creative Computing,
Bath Spa University,
Bath, England
davidhsu@hcu.edu.tw

Terng-Yin Hsu
Department of Computer Science and Information engineering, National Chiao-Tung University
HsinChu, Taiwan
tyhsu@cs.nctu.edu.tw

Hongji Yang
Centre for Creative Computing,
Bath Spa University,
Bath, England
h.yang@bathspa.ac.uk

Yeh-Ching Chung
Research Institute of Tsinghua University in Shenzhen,
Shenzhen 518057, China
Shenzhen, China
yehching.chung@gmail.com

Abstract—**The creative service process is an innovative process that uses newly developed technologies to improve the service models currently used. In this paper, we proposed an IoT-based Cloud-Fog computing platform for the creative service process. The proposed Cloud-Fog computing platform is a distributed computing platform where compute, storage, and network systems of Cloud and Fog are working independently or collaboratively depending on the services performed by the platform. If a service requires resources either from Cloud or Fog, then only the designated Cloud or Fog will be involved. Otherwise, both Cloud and Fog will be collaborated to each other for the service. During the collaboration, the required data may be back and forth in between Cloud and Fog. To demonstrate the usage of the proposed platform for the creative service process, two service examples, smart classroom and city surveillance, are discussed**

Keywords-component; Creative Service Process; Cloud Computing; Fog Computing; Internet of Things

I. INTRODUCTION *(HEADING 1)*

The advancement of computing has enabled broad use of computers in all domains. Over the last decade, the rapid innovation in computing and communication technologies such as Cloud computing [8], Fog computing [2], Internet of Things (IoT) [13], 5G [11], etc., has offered ever faster and more versatile access to ever more data, information and knowledge, which enables the transformative social power of the technology directly or indirectly.

Creative computing [15][16] refers to a meta-technology to coalesce knowledge in computing and other disciplines. People use computers as aids to creativity and creative-computing topics may reshape the world as we know it. Applications are seen in arts, entertainment/games, mobile applications, multimedia, product/web design and other interactive systems.

The creative service research, in general, can be divided into two categories, the creative service process and the creative service result. The creative service process is an innovative process that uses newly developed technologies to improve the service models currently used, that is, the result a service provided is the same but different in the way it is delivered. The creative service result uses an innovative approach to re-permutate the current data used by a service and finds unknow factors that can be used to improve the result of a service. Overall, the creative service process intends to improve the process of a service while the creative service result focuses on improving the result a service delivered.

In this paper, we proposed an IoT-based Cloud-Fog computing platform (ICF) for the creative service process. ICF is a distributed computing platform that consists of a few Clouds (datacenters) and Fogs (or Edge Clouds). The proposed ICF has the following properties:

- The Clouds of ICF form a federated cloud system by running an OpenStack [1] based software called Taiwan UniCloud [6].
- An IoT Box is proposed as the core component of Edge Clouds. An IoT Box is a platform that has compute, storage, and network systems. Based on an application, an IoT Box can be an embedded system, a personal computer, or a server. An Edge Cloud is composed of one or more IoT Boxes.
- A service oriented framework (SOA) is designed to coordinate services provided by Cloud and Fog. With the SOA, services can be carried out statically and/or dynamically by Cloud and Fog based on the requirements of applications.
- The compute, storage, and network systems of Cloud and Fog may work independently or collaboratively for the services carried out in the platform. If a service requires resources either from Cloud or Fog, then only the designated Cloud or Fog will be involved. Otherwise, both Cloud and Fog will be collaborated to each other for the service.

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- The storage systems of Cloud and Fog form a hierarchical storage system. Data stored in Cloud and Fog is historic and up-to-date, respectively. A hybrid file system that is composed of Ceph [14], HDFS [3], and Gluster [7] is used for Cloud, while a container-based cloud storage system, SSBox [5], is used for Fog.
- A 5G network is provided based on the cloud radio access network (C-RAN) architecture [4]. This network is suitable for services require data transferring across IoT network, local area network (LAN), and wide area network (WAN).
- A machine type communication (MTC) network [12] has been designed based on OM2M framework [9]. This network is suitable for services require data transferring across IoT network and local area network.

To demonstrate the usage of the proposed platform for the creative service process, two service examples, smart classroom and city surveillance, are discussed. In the smart classroom example, we demonstrate how to use the proposed platform to provide a creative service process for the classroom preparation and the student attendance record generation. For the surveillance example, we show how a creative service process can be provided to solve a robbery case occurred in a city efficiently.

The rest of the paper is organized as follows. In Section 2, the backgrounds of Cloud and Fog computing are discussed briefly. Section 3 describes the proposed Cloud-Fog computing platform in some details. The examples designed to demonstrate the creative service process performed by the proposed platform are given in Section 4.

II. Background

National Institute of Standards and Technology (NIST) defines Cloud computing as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models (IaaS, PaaS, and SaaS), and four deployment models (public, private, hybrid, and community).

The term of Fog Computing was introduced by the Cisco Systems as a new model to ease wireless data transfer to distributed devices in the Internet of Things (IoT) network. Cisco defines Fog Computing as a paradigm that extends Cloud computing and services to the edge of the network. Fog provides compute, storage, and network services to end-users and facilitates the operations of these services between end devices and cloud computing data centers.

Figure 1. shows a three-tier Cloud-Fog computing architecture. In Figure 1. , mobile devices (or mobile terminal nodes) in tier 1 form virtual clusters. Mobile devices communicate to each other either via smart things network if they are in the same virtual cluster or via edge communication network otherwise. In tier 2, Fog computing devices form Edge Clouds. Fog computing devices communicate to each other either via local area network if they are in the same Edge Cloud or via core network otherwise. In tier 3, datacenters form Clouds. Cloud datacenters communicate to each other via Internet.

Since the compute, storage, and network capabilities provided by the devices in each tier are different, the services can be performed/provided by each tier are different as well. Figure 2. shows an example of the services performed/provided by each layer of the three-tier Cloud-Fog computing architecture shown in Figure 1. . From Figure 2. , we can see that

- Mobile devices in tier 3 can only perform limited/simple data validation services;
- Fog computing devices in tier 2 can perform more complex data validation, storing, and forwarding services;
- Datacenters in tier 1 can perform complex and full data validation, storing, and analytical services.

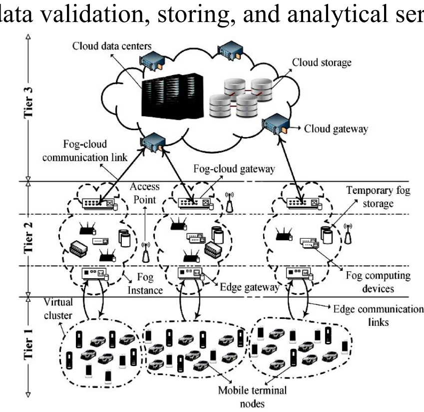

Figure 1. A three-tier Cloud-Fog computing architecture

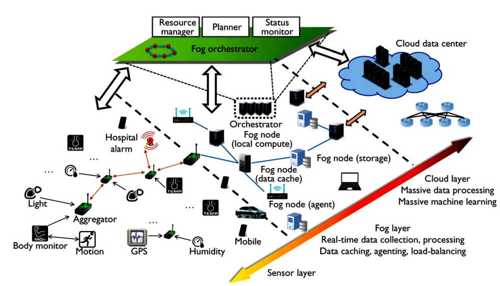

Figure 2. The services performed/provided in each layer

III. The IoT-Based Cloud-Fog Computing Platform

ICF is a 3-tier, IoT Box based, and distributed computing system. The system architecture of ICF is shown in Figure 3. . In Figure 3. , ICF is composed of three components, Cloud, Fog, and IoT. At the Cloud side, several datacenters form a federated/hybrid cloud platform by running an OpenStack based software called Taiwan UniCloud.

At the Fog side, an IoT Box is proposed as the core component of Edge Clouds. An IoT Box is a platform that has compute, storage, and network systems. Based on applications, an IoT Box can be an embedded system, a mini-PC, a low-end desktop, or a high-end server with designated software. An Edge Cloud consists of one or more IoT Boxes.

At the IoT side, several sensors form an IoT cluster. In this paper, we define a sensor as a device that has sensing capabilities. Based on this definition, any device with sensing components is a sensor. For each IoT cluster, there is a HetNet gateway to coordinate the services provided by sensors in the cluster. The HetNet gateway is also responsible for the communication between sensors using different communication protocols.

Cloud datacenters and Edge Clouds communicate to each other via Internet while Edge Clouds and IoT clusters communicate to each other via Wifi, 4G LTE or 5G C-RAN. Sensors in IoT clusters communicate to each other via Wifi, Zigbee, Bluetooth, or machine-to-machine (M2M) networks. In the following, we will describe the compute, storage, and network systems of ICF in some details.

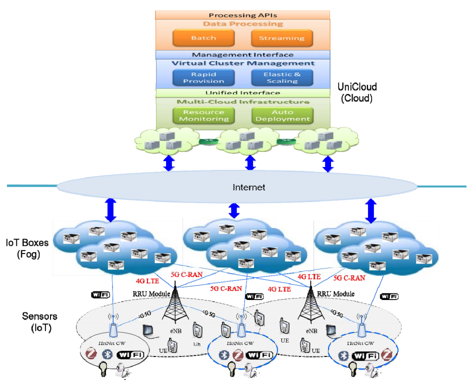

Figure 3. The system architecture of ICF

A. *The compute system of ICF*

The compute components of Clouds (Datacenter servers), Fogs (IoT Boxes), and IoTs (sensors) form a distributed and heterogeneous computing system in ICF. In ICF, each compute component can work independently or work with others collaboratively depending on applications. An IoT Box is a platform that has compute, storage, and network systems. It is the core of Edge Clouds. It can be an embedded system, a mini-PC, a low-end desktop, or a high-end server with designated software to provide certain services. Based on applications, an Edge Cloud can be composed of one or more IoT Boxes. In this paper, IoT Boxes are used as IoT HetNet Gateways (using Raspberry PIs), Surveillance Boxes (using Intel NUCs), Smart Classroom Boxes (using low-end PCs), and 5G C-RAN Boxes (using high-end servers). Figure 4. shows examples of IoT Boxes.

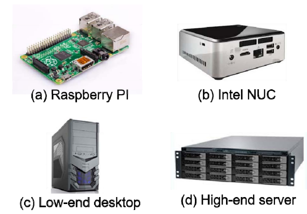

Figure 4. Examples of IoT Boxes

Based on the computing capabilities of different compute components, a service may be carried out in a single compute component or across several compute components. To coordinate services provided in ICF, a service oriented framework is needed.

Figure 5. shows the architecture of the proposed service oriented framework for IoT Boxes. The framework is designed based on OM2M. It has two layers, IoT service management and IoT service layers. The IoT service management layer provides two functions, service subscription and publishing, and a service controller. The service subscription function is used to record the services an IoT Box subscripted from other IoT Boxes. The service publishing function is used to publish services an IoT Box provided and maintains a device list for each service that has been subscripted.

Services provided by an IoT Box can be deployed statically or dynamically. In general, an IoT Box provides some fixed services based on an application. These fixed services can be deployed statically. However, services may be inserted to an IoT Box to perform certain tasks in some time spans. For these kinds of services, they are deployed dynamically. In addition, services provided by an IoT Box may not function properly due to some reasons. When this situation occurs, the malfunction service should be suspended until the causes are solved. The service controller is responsible for the dynamic service deployment and malfunction service suspension.

The IoT service layer is responsible for the service execution, data manipulation, and resource management.

With the service oriented framework, services can be deployed and executed in ICF statically and/or dynamically on Cloud and/or Fog based on the requirements of applications.

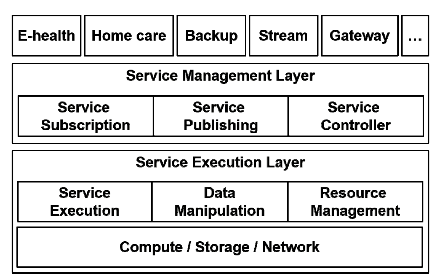

Figure 5. A service oriented framework for IoT Box

B. The storage system of ICF

The storage components of servers and IoT Boxes form a distributed and hierarchical storage system for ICF as shown in Figure 6. . In this storage hierarchy, data stored in Fog is the most up-to-date since it is collected from sensing devices directly. Based on the data placement police, data stored in the storage system of IoT Boxes is sync/backup to the storage system of Clouds after a period of time. Data may be back and forth in between the storage system of Clouds and IoT Boxes if a service requires resources across Clouds and Fogs.

To manipulate data, at the Cloud side, a hybrid file system, call HybridFS 0, is used. HybridFS is composed of multiple distribute file systems with the integration of advantages of these distributed file systems. In HybridFS, on top of multiple distributed file systems, a metadata management server is developed to perform three functions: file placement, partial metadata store, and dynamic file migration. The file placement is performed based on a decision tree. The partial metadata store is performed for files whose sizes are less than a few hundred bytes to increase throughput. The dynamic file migration is performed to balance the storage usage of distributed file systems without throttling performance. From the experimental test, HybridFS can have up to 30% performance improvement of read/write operations over a single distribute file system. In addition, if the difference of storage usage among multiple distributed file systems is less than 40%, the performance of HybridFS is guaranteed, that is, no performance degradation.

At the IoT Box side, a cloud storage system SSBox is used to manage data collected from sensing devices and performs sync/backup operations with the storage system in Clouds. SSBox provides cloud storage services such syncing, upload, download, sharing, streaming, backup, etc. The SSBox system is mainly composed of Nginx, Memcached, PostgreSQL, Server-core and a file system. The Nginx is an inverse proxy service that redirects incoming queries to Server-core. The Server-core is responsible for APIs management and communication with PostgreSQL. The PostgreSQL is a database to store information such as metadata, user accounts, etc. The Memcached is an in-memory database that could improve the performance in download scenario. Clients can access SSBox via web browser, iPhones, and Android phones.

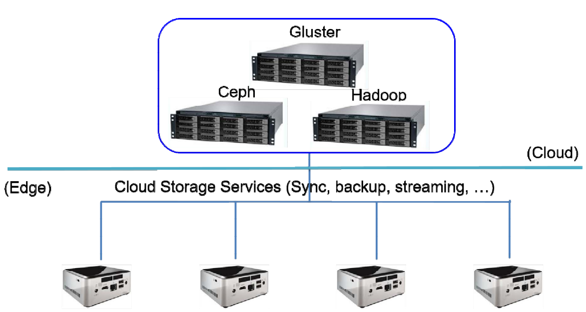

Figure 6. A distributed and hierarchical storage system of ICF

C. The network system of ICF

The network system of ICF contains core network, 5G C-RAN, IoT network. Figure 7. show the architecture of the 5G/IoT networks proposed in ICF.

5G network

In Figure 7. , a 5G network is developed based on Open Air Interface (OAI) [10] that is an open source project led by EUROCOM. OAI is designed based on the cloud radio access network (C-RAN) architecture proposed by China Mobile Research Institute. C-RAN is a centralized, cloud computing-based architecture for radio access networks that supports 2G, 3G, 4G and future wireless communication standards. Since the specification of 5G is not ready yet, the design of OAI is based on the most advanced 4G technology.

The current OAI design has some drawbacks. The major one is that its performance is far behind the requirements of 5G. The main reason is that the software of physical, MAC, and application layers of a baseband station are all in a module. This kind of design limit the scalability of OAI. In addition, the software does not take the advantages of accelerators such as GPU. In our design, we decouple OAI into three modules based on the physical, MAC, and application layers and sue GPU to accelerate the execution of each module. Currently, our OAI version can deliver 200+ Mbps transmission rate and the communication latency is less than 1 ms.

The proposed OAI-based 5G C-RAN network can be operated independently as a private network or be collaborated with public 4G networks operated by telecommunication companies.

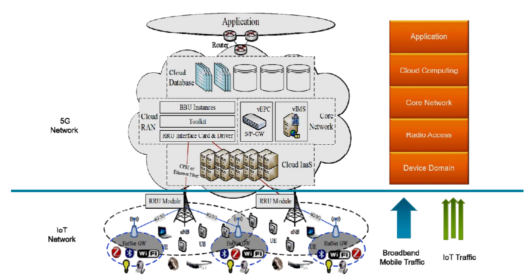

Figure 7. The 5G/IoT networks of ICF

IoT network

In order to manage the sensors in a flexible and efficient way, a machine type communication (MTC) network based on a novel M2M framework using smart/HetNet gateways is proposed. The proposed IoT network is not only compatible to the M2M standard, but also enables the community-based coordination among gateways and devices. With smart and HetNet gateways, different requirements and applications can be fulfilled and handled at a local region. Accordingly, unnecessary network usage is avoided and the traffic loads are reduced in mobile networks.

In the proposed IoT network, the HetNet gateway is used to coordinate the communication between sensors using different protocols. In addition, it is used to coordinate all services provided by sensors that are connected to it. The smart gateway is used to coordinate all HetNet gateways connected to it, handles the communication with other smart gateways and/or Clouds, and performs some designated services.

Figure 8. shows a use case of the proposed IoT network. In Figure 8. , an LED control example with smart and HetNet gateways is given. In this example, there are two sensors, an LED with Bluetooth protocol and a camera with Wifi protocol. The HetNet gateway is an IoT Box that can handle both Wifi and Bluetooth protocols. It is designed based on Raspberry PI. The smart gateway is an IoT Box as well and provides a face recognition service. It is designed based on Intel NUC. The camera takes a picture every second and send the picture to the smart gateway via HetNet gateway for validation. If the face recognition service provided in the smart gateway detects a face appeared three times consecutively, the smart gateway will send a turn-on signal via HetNet gateway to LED. Otherwise, the smart gateway will send a turn-off signal via HetNet gateway to LED.

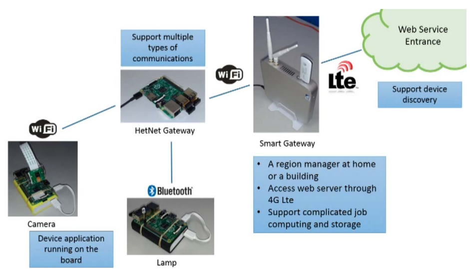

Figure 8. An LED control example with smart and HetNet gateways

IV. Cases Study

In this section, we study two cases, smart classroom and city surveillance, to demonstrate the usage of ICF for creative service process.

A. *Case 1 - Smart classroom*

Figure 9. shows the scenario of a smart classroom. In this scenario, the Office of Academic Affair of a university has the class schedule of each classroom, the PPT of each course, the student enrollment list of each course, and the student attendance record of each course. All files mentioned above are stored in Clouds. In a smart classroom, an IoT Box is used to control ON and OFF of air conditioners, curtains, a camera, lights, an overhead project, and doors. The IoT provides two services, face recognition and student attendance record statistics.

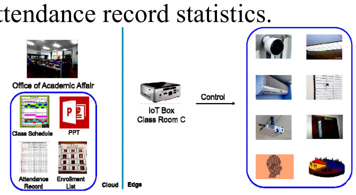

Figure 9. The scenario of a smart classroom

In a tradition classroom, a staff is needed to open and close doors, close and open blinds, and turn-on and turn-off air conditioners, camera, lights, and overhead projector before and after the class, respectively. A teacher needs to install his/her PPT to the PC in the classroom before teaching. The teacher or a staff needs to named students officially or unofficially 5 minutes before the end of class in order to update the student attendance record for his/her own or the Office of Academic Affair's reference, respectively.

With the smart classroom, 5 minutes before class, the IoT Box will open doors, close blinds, turn-on air conditioners, camera, lights, and overhead projector. The PPT of the course, the student enrollment list of the course, and the student attendance record of the course will be pushed to the IoT Box. After these files received, the IoT Box will open the PPT for the teacher. Five minutes before the end of class, the IoT Box will launch the face recognition and the student attendance record statistics services to named students automatically. At the end of the class, the IoT Box will send the newly updated student attendance record of the course back to the Office of Academic Affair. Five minutes after the class, the IoT Box will turn-off air conditioners, camera, lights, and overhead projector, open blinds, and close doors.

From the case study shown above, we can see that the smart classroom indeed provides create service processes for the traditional classroom management and the student attendance record generation.

B. *Case 2 - City Surveillance*

Figure 10. shows the scenario of a city surveillance. In this scenario, cameras are all over in a city such as in cars, cross roads, buildings, etc. These cameras are connected to IoT Boxes. Videos captured by cameras are stored at IoT Boxes for a week. After a week, all videos are uploaded to Cloud datacenters. The Cloud side provides services such as suspect detection, suspect action path tracking, etc.

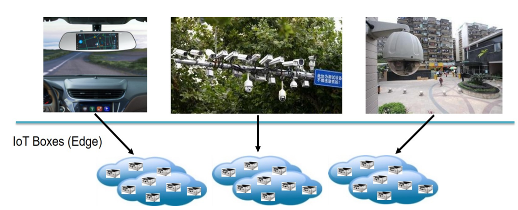

Figure 10. The scenario of a city surveillance

Traditionally, when the public security command center (PECC) receive a call at time T to report a robbery occurred in location A, the corresponding officers need to look at all videos around the robbery location, find a few possible suspects, figure out the action path of these suspects, and then take proper actions. The process may take a few days to a few months depending to the videos available.

With IoT Boxes, PECC can take the following actions:

1. PECC pushes a suspect detection service to those IoT Boxes that are one hour before and after time T in one-mile radius of location A.
2. Each involved IoT Box finds the top five suspects from videos it recorded and sends them back to PECC.
3. PECC selects top five suspects from those suspects sent by IoT Boxes.
4. PECC sends an action path tracking service along with the information of five suspects to IoT Boxes.
5. Each IoT Box finds the action path of each suspect and send them back to PECC.
6. PECC composes the action path of each suspect from those sent by IoT Boxes and takes proper actions.

From the case study shown above, we can see that the proposed ICF indeed provides a create service process to solve the robbery case compared to the traditional approach.Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

C. Units

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as “3.5-inch disk drive”.
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: “Wb/m2” or “webers per square meter”, not “webers/m2”. Spell out units when they appear in text: “. . . a few henries”, not “. . . a few H”.
- Use a zero before decimal points: “0.25”, not “.25”.

V. Conclusions and Future Work

In this paper, the compute, storage, and network systems of the proposed ICF are described in some details. The concept of IoT Box is also introduced since it is a key component of ICF and plays important roles in ICF. To demonstrate the usage of ICF for creative service research, two cases, smart classroom and city surveillance, were studied. The study results show that ICF indeed provides creative service processes for the studied cases compared to the tradition processes.

For the two cases study, we only demonstrate the usability of ICF for creative service process and did not give detailed performance analysis. In the future, we will implement the smart classroom at Hsuan-Chuang University and conduct the performance analysis. For the city surveillance case, we will discuss with Hsin-Chu City Government for the possible collaboration. The proposed ICF can also be applied to other research domains such as big data, smart city, etc. We will explore the applications of ICF in these areas as well.

References

[1] Amr Abdelrazik, Greg Bunce, Kathy Cacciatore, Kenneth Hui, Sridhar Mahankali, and Frans Van Rooyen, “Adding Speed and Agility to Virtualized Infrastructure with OpenStack,” Openstack white paper, 2015.

[2] Maher Abdelshkour, "IoT, from Cloud to Fog Computing," Cisco Blogs, 2015.

[3] Dhruba Borthakur. HDFS Architecture Guide. HADOOP APACHE PROJECT http://hadoop.apache. org/common/docs/current/hdfs design. pdf, page 39, 2008.

[4] China Mobile Research Institute (2011), “C-RAN: The Road Toward Green RAN,” White Paper, 2011.

[5] Hsing-Chang Chou, Che-Rung Lee, and Yeh-Ching Chung. (2015) Container-Based Scale-Out Architecture for Cloud Storage Service. Master Thesis, National Tsing Hua University.

[6] Wu-Chun Chung, Po-Chi Shih, Kuan-Chou Lai, Kuan-Ching Li, Che-Rung Lee, Jerry Chou, Ching-Hsien Hsu, and Yeh-Ching Chung, "Taiwan UniCloud: A Cloud Testbed with Collaborative Cloud Services," Proceedings of IEEE International Conference on Cloud Engineering (IC2E), March 2014, pp. 107-116.

[7] GlusterFS. https://www.gluster.org/docs-redirect/. 2016.

[8] Peter Mell and Timothy Grance, “The NIST Definition of Cloud Computing,” NIST Special Publication 800-145, 2011.

[9] OM2M - Open Source platform for M2M communication, http://www.eclipse.org/om2m/.

[10] OpenAirInterface, http://www.openairinterface.org/.

[11] Afif Osseiran, Federico Boccardi, Volker Braun, Katsutoshim Kusume, Patrick Marsch, Michal Maternia, Olav Queseth, Malte Schellmann, Hans Schotten, Hidekazu Taoka, Hugo Tullberg, Mikko A. Uusitalo, Bogdan Timus and Mikael lgren, “Scenarios for 5G mobile and wireless communications: the vision of the METIS project,” IEEE Communications Magazine, 52 (5), 2014, pp. 26–35.

[12] Tarik Taleb and Andreas Kunz, “Machine Type Communications in 3GPP Networks: Potential, Challenges, and Solutions,” IEEE Communications Magazine, Vol. 50, No. 3, 2012, pp. 178-184.

[13] Ovidiu Vermesan and Peter Friess, *Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems*, Aalborg, Denmark: River Publishers. ISBN 978-87-92982-96-4.

[14] Sage A. Weil, Scott A. Brandt, Ethan L. Miller, Darrell DE. Long, and Carlos Maltzahn, “Ceph: A Scalable, high-Performance Distributed File System,” In Proceedings of the 7th symposium on Operating Systems Design and Implementation, USENIX Association, 2006, pp. 307–320.

[15] Hongji Yang, Editorial, International Journal of Creative Computing, Vol.1 No. 1, 2013, pp. 1-3.

[16] Hongji Yang and Lu Zhang, “Promoting Creative Computing: origin, scope, research and applications,” Digital Communication and Networks, Vol. 2, 2016, pp. 84-91.

Lidong Zhang, Yongwei Wu, Ruini Xue, Tse-Chuan Hsu, Hongji Yang, and Yeh-Ching Chung, "HybridFS - A High Performance and Balanced File System Framework with Multiple Distributed File Systems," To appear in *Proceedings of IEEE Computer Software and Applications Conference* (COMPSAC), July 2017.