Fog Computing and Smart Gateway Based Communication for Cloud of Things

Mohammad Aazam[1], Eui-Nam Huh[2]
Innovative Cloud and Security Lab, Department of Computer Engineering
Kyung Hee University, Suwon, South Korea.
[1]aazam@ieee.org
[2]johnhuh@khu.ac.kr

Abstract— **With the increasing applications in the domains of ubiquitous and context-aware computing, Internet of Things (IoT) are gaining importance. In IoTs, literally anything can be part of it, whether it is sensor nodes or dumb objects, so very diverse types of services can be produced. In this regard, resource management, service creation, service management, service discovery, data storage, and power management would require much better infrastructure and sophisticated mechanism. The amount of data IoTs are going to generate would not be possible for standalone power-constrained IoTs to handle. Cloud computing comes into play here. Integration of IoTs with cloud computing, termed as Cloud of Things (CoT) can help achieve the goals of envisioned IoT and future Internet. This IoT-Cloud computing integration is not straight-forward. It involves many challenges. One of those challenges is data trimming. Because unnecessary communication not only burdens the core network, but also the data center in the cloud. For this purpose, data can be preprocessed and trimmed before sending to the cloud. This can be done through a Smart Gateway, accompanied with a Smart Network or Fog Computing. In this paper, we have discussed this concept in detail and present the architecture of Smart Gateway with Fog Computing. We have tested this concept on the basis of Upload Delay, Synchronization Delay, Jitter, Bulk-data Upload Delay, and Bulk-data Synchronization Delay.**

Keywords—IoT; cloud computing; CoT; smart gateway; fog computing

I. INTRODUCTION

Internet of Things (IoT) [2] is no more a buzzword now. Productive work is going on in this area of next generation Internet. IoT's and cloud computing need to be integrated, since IoTs are going to expand and produce a lot of data. With the trend going on, in near future, number of connected devices would be hundreds of times larger than the number of people connected. Since 2012, 20 households have been generating more Internet traffic than the whole Internet used to do in year 2008 [1].

A. Internet of Things

Internet of Things (IoT) is set to become the next big thing after the introduction of Internet itself. Millions and probably billions of 'smart' devices are expected to connect to each other and exchange data and information over the internet. The advocates of the IoT envision nearly all aspects of our life to be covered by these smart devices. The sensors are typical examples of such smart devices. IoT, being the technological revolution, represents the future of connectivity and reachability. In IoT, 'things' refer to any object on the face of the Earth, whether it is a communicating device or a non-communicating dumb object. From a smart device to a leaf of a tree or a bottle of beverage, anything can be part of Internet. The objects become communicating nodes over the Internet, through data communication means, primarily through Radio Frequency Identification (RFID) tags. IoT include smart objects as well. Smart objects are those objects which are not only physical entities, but also digital ones and perform some tasks for humans and the environment. This is why IoT is not only hardware and software paradigm, but also include interaction and social aspects as well [3]. IoT also presents many possible scenarios where heterogeneous devices interact with each other and then pass on the information to a central authority. IoT provides opportunities for network operators to provide services to the manufacturers, vendors, and end user to generate more revenue.

IoT works on the basis of Machine-to-Machine (M2M) communication, but not limited to it. M2M refers to communication between two machines without human intervention. In IoT, even non-connected entities can become part of IoT, with a data communicating device, like Bluetooth,

978-1-4799-4357-9/14 $31.00 © 2014 IEEE
DOI 10.1109/FiCloud.2014.83

bar-code, or an RFID tag, sensed through a device (may even be a smart phone sensing it), which eventually is connected to the Internet. In IoT, non-intelligent objects, known as ‘things’ in IoT terminology, become the communicating nodes.

The architecture of IoT is usually considered to be 3-layer, having Perception layer, Network layer, and Application layer, but some [2], [4] add two more layers: Middleware layer and Business layer. This five layer architecture is described in figure 1.

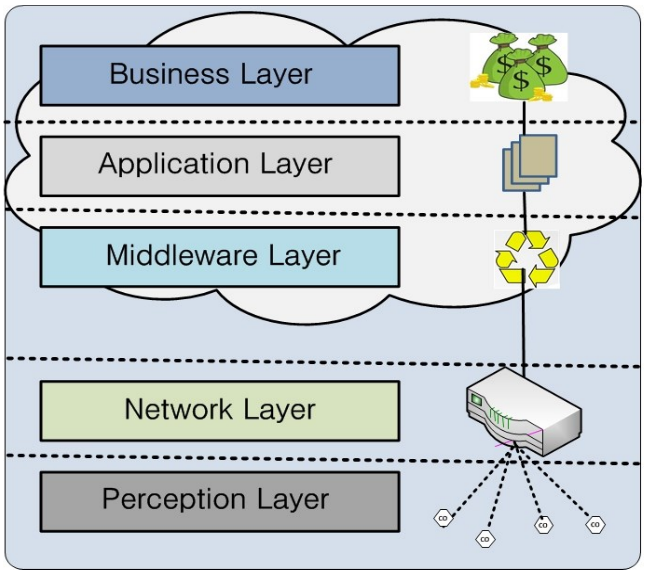

Figure 1. Internet of Things layers

Perception layer is the lowest layer in the IoT architecture. As the name suggests, its purpose is to perceive the data from environment. All the data collection and data sensing part is done on this layer [5]. Sensors, bar code labels, RFID tags, GPS, and camera, lie in this layer. Identifying object/thing and gathering data is the main purpose of this layer.

Network layer collects the data perceived by the Perception layer. Network layer is like the Network and Transport layer of OSI model. It collects the data from the lower layer and sends to the Internet. Network layer may only include a gateway, having one interface connected to the sensor network and another to the Internet. In some scenarios, it may include network management center or information processing center.

Middleware layer receives data from Network layer. Its purpose is service management and storage of data. It also performs information processing and takes decisions automatically based on results. It then passes the output to the next layer, the Application layer [4].

Application layer performs the final presentation of data. Application layer receives information from the Middleware layer and provides global management of the application presenting that information, based on the information processed by Middleware layer. Depending upon the type of devices and their purpose in Perception layer and then on the way they have been processed by the Middleware layer, according to the requirement of user, Application layer presents the data in the form of: smart city, smart home, smart transportation, vehicle tracking, smart farming, smart health and other many kinds of applications [4].

Business layer is all about how the service or model works. It is about making money from the service being provided, however, non-profit and government owned efforts involved in IoT may also be part of it. Data received at the application layer is molded into a meaningful service and then further services are created from those existing services. Furthermore, information is processed to make it knowledge and further efficient means of usage make it wisdom, which can earn a good amount of money to the service provider.

B. *Cloud Computing*

Cloud computing, the recent trend in IT, takes computing from desktop to the whole World Wide Web and yet, the user does not need to worry about maintenance and managing all the resources. User has to bear only the cost of usage of service(s), which is called pay-as-you-use in cloud computing terms. With this cloud computing, a smart phone can become an interface to large data center. Cloud computing is extended form of distributed computing, parallel computing, and grid computing [6], [7], [8], and [9]. Cloud computing provides ubiquitous access to the content, without the hassle of keeping large storage and computing devices. Sharing large amount of media content is another feature that cloud computing provides. Cloud computing recently has emerged and advanced rapidly as a promising as well as inevitable technology. Cloud computing platform provides highly scalable, manageable and schedulable virtual servers, storage, computing power, virtual networks, and network bandwidth, according to user’s requirement and affordability. Media management is among the key aspects of cloud computing, since cloud makes it possible to store, manage, and share large amounts of digital media [12]. Cloud computing is a handy solution for processing content in distributed environments. Cloud computing provides ubiquitous access to the content, without the hassle of keeping large storage and computing devices.

In this paper, we present the need of smart communication, on the basis of Smart Gateway and Fog computing. Rest of the paper is organized in such a way that section II presents the integration of IoT and cloud computing, which we term as Cloud of Things. Section III presents Smart Gateway and Fog computing based smart communication. Section IV is on the performance evaluation. We conclude this paper in section V.

II. Cloud of Things

We are moving towards web3, the ubiquitous computing web. Since 2011, number of connected devices has already exceeded the number of people on Earth. Already, connected devices have reached 9 billion and are expected to grow more rapidly and reach 24 billion by 2020 [10]. Since number of connected devices is rapidly increasing, so there is going to be a lot of data as well [11]. Storing that data locally and temporarily will not be possible any more. There is going to be a need of rental storage space. Also, this huge amount of data must also be utilized in the way it deserves. Data must not only be processed to form information and further to form knowledge, but it should be made a mean of wisdom for the user. This asks for more processing which is not possible at the IoT end, where devices are low cost and light-weight. Again, processing and computation must also be available there on rental basis. All this is possible with cloud computing. IoT and cloud computing working in integration makes a new paradigm, termed as Cloud of Things (CoT) [13], [14].

CoT helps manage IoT resources and provide more cost-effective and efficient means to produce services. CoT creates a new and extended portfolio of services. With CoT, the services to be provided are in the cloud, it gives ubiquitous access to the users, extending the scope of usage of the services as well as ease in accessing it. This in turn helps generating more money from the services. Analyzing the IoT-generated data and reacting on delay sensitive and emergency related data also becomes more effective with CoT. Figure 2 presents an overall communication pattern of CoT.

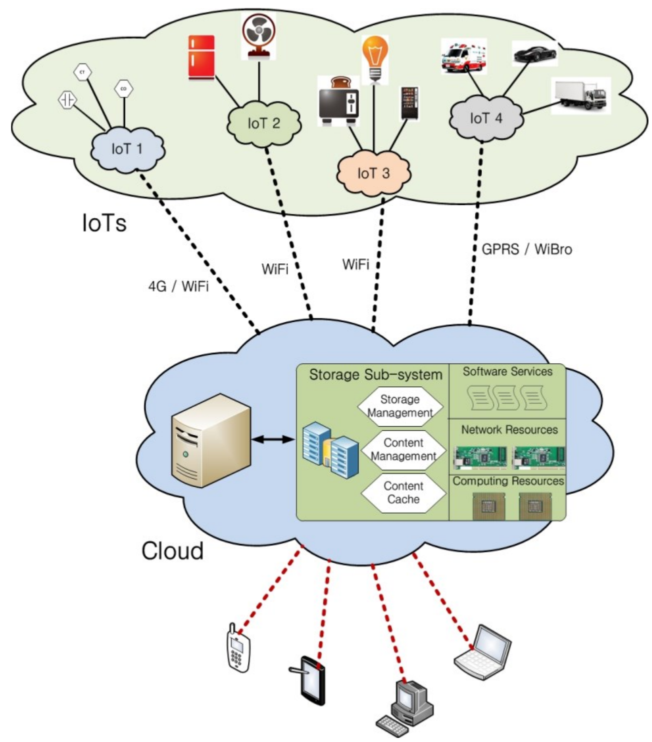

Figure 2. Cloud of Things – data communication

III. Fog Computing and Smart Gateway Based Communication

When anything would be able to connect to the Internet and generate data, there is a possibility that at some stage it is no longer necessary to upload the data to the cloud or sync device. Momentarily, the data may not be required. In that scenario, either the device must be stopped from generating data or gateway device must decide when it is required to stop uploading the data and not to consume resources of the network and cloud, for that while. It will also help in efficient utilization of power. For this purpose, the gateway device connecting IoT to the cloud should be having extra functionality to do a little processing before sending it to the Internet and eventually to the cloud. Based on the feedback from application, gateway must decide the timings and type of data to be sent. This kind of a gateway, we refer it as “Smart Gateway” [13], [14], would help in better utilization of network and cloud resources. The data collected from wireless sensor networks and IoTs will be transmitted through gateways to cloud. The received data is then stored in the cloud and from there, it is provided as a service to the users.

A. Smart Gateway architecture

Smart Gateway has to manage various aspects of underlying IoTs. Smart Gateway performs a number of tasks, like, collecting the data and performing preprocessing, filtering the data and reconstructing it into more useful form, uploading only necessary data to the cloud, keeping check on IoT objects and sensors' activities, keeping check on energy consumption of power constrained nodes of IoTs, security and privacy of the data, and overall service monitoring and management. There is a possibility that the data gathered from IoT is transmitted directly to the Smart Gateway, or multiple IoTs are connected with base station(s), which in turn transmits the data to the Smart Gateway. Smart Gateway based communication can thence be divided into two types.

1). Single-hop communication with the Smart Gateway

In single-hop connectivity, sensor nodes and 'things' are directly connected to the gateway, which then assembles the data and sends to the Fog and then to the cloud. In most of the cases, this kind of communication is on a smaller magnitude, where sensing nodes are not diversely populated and have restricted roles, for example, smart health and ubiquitous healthcare related sensors can be directly connected to the gateway. This provides a quick monitoring and response based communication. Gateway can further send the data to the Fog and then to the cloud. Machine to machine (M2M) based communication would be taking place in this scenario. Data refinement, filtering, trimming, and security measures can be taken at Smart Gateway's end, based on the application demands, along with Fog computing. The extent of this type of communication depends upon the capabilities of the gateway device.

2). Multi-hop communication with the Smart Gateway

When multiple sensors networks and IoTs are connected, direct connection would not be possible anymore. IoTs and sensor networks would be having their own sink nodes and base stations. Gateway collects the data from those base stations and sink nodes, creating a multi-hop communication scenario. In this scenario, the nodes would be diverse and more widely spread. Data would also be more heterogeneous, requiring more processing and extensive data analysis from the gateway. But sink nodes add another layer to the communication, with which, underlying sensors and 'things' become a black box to the outer layer. This adds more security. In this way, security can be customized, according the IoT and wireless sensor network (WSN). Sink nodes can handle sensor networks according to their constraints. In this scenario, gateway would be required to handle heterogeneous data, collected from heterogeneous devices, IoTs, and WSNs. So, transcoding and interoperability would be required as well. Either the gateway must be intelligent enough, or this can be achieved through Fog computing resources. This kind of scenario is also suitable for mobile objects and large scale IoTs/WSNs, like vehicle tracking IoTs, environmental monitoring, and other such examples.

B. Fog Computing

Fog Computing refers to bringing networking resources near the underlying networks. It is a network between the underlying network(s) and the cloud(s). Fog Computing extends the traditional Cloud Computing paradigm to the edge of the network, enabling creation of refined and better applications or services. Fog computing is a highly virtualized platform, which provides computation, storage, and networking services between the end nodes in an IoT and traditional Clouds [15]. Fogs are not exclusively located at the edge of network. In contrast to the cloud, which is more centralized, Fog computing targets the services and applications with widely distributed deployments. The Fog will be able to deliver high quality streaming to mobile nodes, like moving vehicles, through proxies and access points positioned accordingly, like, along highways and tracks. Fog suits applications with low latency requirements, video streaming, gaming, augmented reality, etc. For smart communication, Fogs are going to play an important role. For many of the tasks a gateway has to perform, it is not possible for a gateway to do effectively being standalone. The underlying nodes and networks are not always physical. Virtual sensor nodes and virtual sensor networks are also requirements for various services. Similarly, temporary storage, preprocessing, data security and privacy, and other such tasks can be done easily and more efficiently in the presence of a smart network or Fog, co-located with the Smart Gateway. Since Fog is localized, it provides low latency communication and more context awareness. Fog computing allows real-time delivery of data, specially for delay sensitive and healthcare related services. It can perform the preprocessing smart tasks and notify the cloud, before cloud could further adapt that data into enhanced services. With heterogeneous nodes, heterogeneous type of data would be collected. Interoperability and transcoding becomes an issue then. Fog plays a very vital role in this regard. Also, IoT and WSN federation, in which two or more IoTs or WSNs can be federated at one point, through the Fog, it can be made possible. This will allow creation of rich services. Fog and Smart Gateway based communication architecture is presented in figure 3.

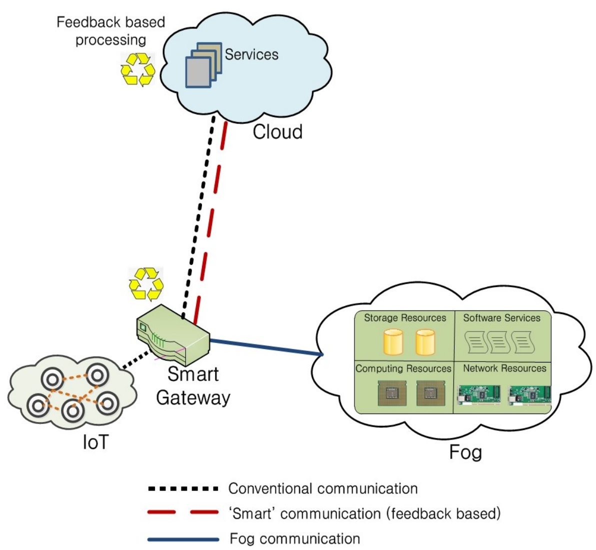

Figure 3. Smart Gateway with Fog computing/Smart network

Keeping in view all these things, the Smart Gateway is presented in layered architecture in figure 4. In the Physical and Virtualization layer, physical nodes, WSNs, virtual nodes, and virtual sensor networks are managed and maintained according to the needs. Monitoring layer monitors the activities of the underlying nodes and networks. Which node is performing what task, at what time, and what is required from it next is monitored here. Other than this, the power constrained devices or nodes are monitored on their energy consumption basis as well, so that effective measures can be taken in time. Preprocessing layer performs data management related tasks. It analyzes the collected data, performs data filtering, trimming, and in the end, more meaningful and necessary data is generated. Data is then temporarily stored on the Fog resources. Once the data is uploaded on the cloud and it is no more required to be stored locally, that data is then removed from the storage media. IoTs and WSNs may generate some private data as well. Ubiquitous healthcare and smart healthcare services generate private data of the patients. Similarly, location aware data may also be sensitive in some cases, which should be made secure. This is where Security layer comes into play. In the end, at Transport layer, the ready-to-send data is uploaded to the cloud, burdening the core to the minimum and allowing cloud create more useful services.

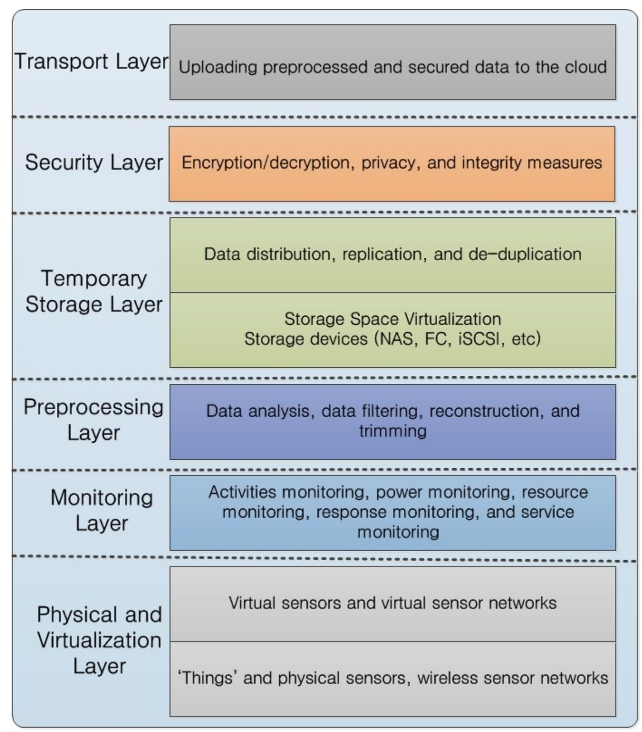

Figure 4. Layered architecture of Smart Gateway with Smart Network/Fog.

IV. Performance Evaluation

In this section, we present performance evaluation of communication between the gateway and cloud. Evaluation was done on a test-bed, involving gateway device and cloud. For this evaluation, two types of data sets were used: (a). multimedia (audio/video) file and (b). bulk-data. For those IoTs, which generate audio or video data, like visual sensor network, multimedia file data-set is used for the evaluation. On the other hand, bulk-data set is constituent of heterogeneous files, having different file formats, sizes, and types. This data set is used to evaluate the communication of those IoTs which have heterogeneous types of sensors and multiple IoTs' data is collectively sent by the gateway to the cloud. For different file types, different scheduling algorithms are used by the cloud. For example, shortest-job-first, first-in-first-out, etc., which have their own impact on the overall performance of data storage in the cloud. To ensure that the network condition does not affect the performance drastically, we conducted this evaluation exhaustively for six weeks, on different sets of weekdays and weekends, during different times of the days. The results were eventually averaged.

Shown in table 1, uploading a 20MB video file to the cloud takes about 70 seconds. This is hence the average time to upload the stated size of video or multimedia data on the cloud.

TABLE 1: UPLOAD DELAY

Data size	20 MB
Upload Delay	70 sec

When an already uploaded content is to be relocated in the cloud or its attributes are changed, the cloud has to re-configure its URL, since every file has a unique web identity in the cloud. This relocation or change in the attributes requires synchronization. For a service being accessed by more than one node or user, collaborative environment is created, which requires more time to synchronize and update the contents. Average time to synchronize data is shown in table 2.

TABLE 2: SYNCHRONIZATION DELAY

Data size	*All*
Synchronization Delay	04 sec
Synchronization Delay for Collaborative work	09 sec

For multimedia content, jitter can be important at times. Cloud has to perform different types of transcoding of multimedia for the receiving devices. Also, different IoTs generating different contents have to be gathered and harmonized for one type of service, the cloud has to provide. Transcoding affects the performance of the cloud and in the end, may cause unexpectedly jittery traffic. Figure 5 represent jitter, while figure 6 shows variance and standard deviation in jitter.

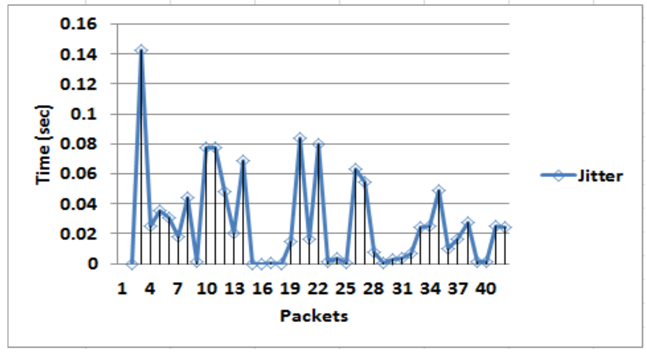

Figure 5. Jitter, experienced from cloud.

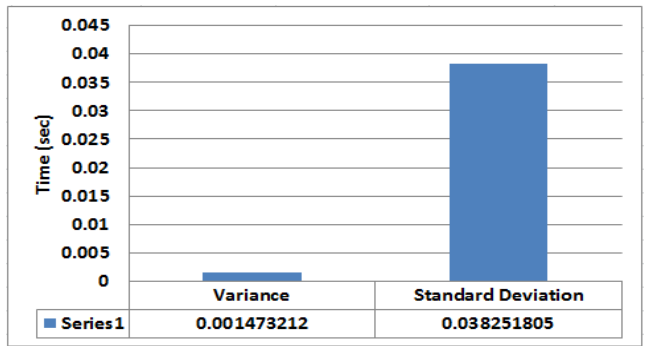

Figure 6. Variance and Standard Deviation in terms of Jitter.

In the second form of evaluation, bulk-data was used. We used up to 100MB datasets, but for simplicity sake, only 10MB bulk-dataset evaluation is shown here. Table 3 shows how much multitude of files incur delay.

TABLE 3: BULK-DATA UPLOAD DELAY

Data size	10 MB
Bulk-data Upload Delay	28 sec

In terms of synchronization delay for bulk-data, as different types of files are to be updated, it requires more time. Table 4 shows that compared with single 20MB file (table 2), bulk-data of 10MB take more than twice as much time in synchronizing files.

TABLE 4: BULK-DATA SYNCHRONIZATION DELAY

Data size	*All*
Synchronization Delay	~ 09 sec

V. CONCLUSION AND FUTURE WORK

This paper discusses about the expanding IoTs and their integration with cloud computing, for enhanced and more useful service provisioning to the user and efficient utilization of resources. For better and quick service provisioning, trimming and pre-processing the data before sending to the cloud is very important. We have presented Smart Gateway based communication, along with Fog computing, for the purpose of smart communication and help lessen the burden on cloud. It also helps alleviate communication overhead for the core network. This approach makes it easy for the cloud to create better services more efficiently and with Fog computing, normal communication can be made real-time for delay sensitive applications. This vision of CoT, smart communication with Smart Gateway and Fog computing will deliver a rich portfolio of services. Furthermore, a comprehensive evaluation of performance is presented, based on various parameters. The extended work could be on the impact of heterogeneous storage and overall performance on the basis of diverse applications.

ACKNOWLEDGEMENT

This research was supported by the MSIP (Ministry of Science, ICT&Future Planning), Korea, under the ITRC (Information Technology Research Center) support program (NIPA-2014(H0301-14-1020)) supervised by the NIPA (National IT Industry Promotion Agency).

This research was also supported by Next-Generation Information Computing Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2010-0020725). The corresponding author is Prof. Eui-Nam Huh.

REFERENCES

[1] Yen-Kuang Chen, “Challenges and Opportunities of Internet of Things”, in the proceedings of 17th Asia and South Pacific Design Automation Conference, 30 Jan. – 02 Feb., 2012, Santa Clara, CA, USA.

[2] Miao Wu et. al., “Research on the architecture of Internet of things”, in the proceedings of 3rd International Conference on Advanced Computer Theory and Engineering, 20-22 August, 2012,Beijing, China,

[3] Gerd Kortuem, Fahim Kawsar, Daniel Fitton, and Vasughi Sundramoorthi, “Smart Objects and Building Blocks of Internet of Things”, IEEE Internet Computing Journal, volume 14, issue 1, pp. 44-51, Jan.-Feb., 2010

[4] Rafiullah Khan, Sarmad Ullah Khan, Rifaqat Zaheer, and Shahid Khan, “Future Internet: The Internet of Things Architecture,Possible Applications and Key Challenges”, in the proceedings of 10th International Conference on Frontiers of Information Technology, Islamabad, Pakistan, 17-19 December, 2012.

[5] Dieter Uckelamann, Mark Harrison, and Floria Michahelles, “Architecting the Internet of Things,” Springer-Verlag Berlin Heidelberg, 2011.

[6] Shuai Zhang et. al., “Cloud Computing Research and Development Trend”, in the proceedings of International Conference on Future Networks, 22-24 Jan., 2010, Sanya, China.

[7] W. Ma et. al., “The Survey and Research on Application of Cloud Computing”, in the proceedings of 7th International Conference on Computerl Science and Education, 02-04 November, 2012, Wuyishan Mountain, China.

[8] Y. Jadeja, et. al., “Cloud Computing - Concepts, Architecture and Challenges”, in the proceedings of International Conference on Computing Electronics and Electrical Technologies, 21-22 March, 2012, Nagercoil, India.

[9] Minqi Zhou et. al., “Services in the Cloud Computing Era: A Survey”, in the proceedings of 4th International Universal Communications Symposium, 18-19 October, 2010, Beijing, China.

[10] Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, and Marimuthu Palaniswami, “Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions”, Technical Report CLOUDS-TR-2012-2, July 2012.

[11] Dave Evans, “The Internet of Things How the Next Evolution of the Internet Is Changing Everything”, Whitepaper, Cisco Internet Business Solutions Group (IBSG), April 2011.

[12] Mohammad Aazam, Eui-Nam Huh, “Inter-Cloud Architecture and Media Cloud Storage Design Considerations”, in the proceedings of 7th IEEE CLOUD, Anchorage, Alaska, USA, 27 June - 02 July, 2014.

[13] Mohammad Aazam, Eui-Nam Huh, “Cloud of Things: Integrating Internet of Things with Cloud Computing and the Issues Involved”, in the proceedings of 11th IEEE International Bhurban Conference on Applied Sciences and Technology, Islamabad, Pakistan, 14-18 January, 2014.

[14] Mohammad Aazam, Eui-Nam Huh, “Smart Gateway Based Communication for Cloud of Things”, in the proceedings of 9th IEEE International Conference on Intelligent Sensors, Sensor Networks, and Information Processing, Singapore, 21-24 April, 2014.

[15] Flavio Bonomi, Rodolfo Milito, Jiang Zhu, Sateesh Addepalli, "Fog Computing and Its Role in the Internet of Things", in the proceedings of ACM SIGCOMM, August 17, 2012, Helsinki, Finland.