Int. J. Res. Ind. Eng. Vol. 7, No. 4 (2018) 482–494

International Journal of Research in Industrial Engineering

www.riejournal.com

Cloud-Based IoT: Integration Cloud Computing with Internet of Things

J. Pourqasem *

Department of Computer Engineering, Ayandegan Institute of Higher Education, Tonekabon, Iran.

A B S T R A C T

Internet of Things (IoT) technology is based on interconnected things in a dynamic and distributed environment. The IoT contains many widely pervasive and heterogeneous small things with limited storage, energy resources, and processing capacities. These limitations are an obstacle for developing IoT applications and involve challenging issues such as interoperability, scalability, performance, and availability. Cloud Computing is one of the promising approaches that can be integrated with IoT to overcome these limitations. The Cloud provides shared resources (network, storage, computing, and software) and is characterized by ubiquitous, low-cost, and virtualization features. This paper presents the Cloud-based IoT platform and describes the communication, processing, and storage properties of it. This platform can benefit from the resources and services of the Cloud to collect, transmit, analyze, process, and store the data generated by the heterogeneous things. We also represent the projects that have implemented the Cloud-based IoT platform.

Keywords: IoT, Cloud, OpenIoT.

Article history: *Received: 05 Auguestv2018* *Revised: 03 October 2018* *Accepted: 19 December 2018*

1. Cloud-Based Internet of Things

Internet of Things technology is characterized by the real world and huge small things with the limited storage, processing capacity, and energy and short-range communications [9, 36, 42, 43, 44]. Collecting, storage, and process the IoT data locally is becoming impractical due to the number of sensors and the volume of data they generate [10, 45]. Furthermore, the IoT connects the objects, devices, and humans and generates the large volumes of data. Accessing these data by the organizations can be a complex process due to the heterogeneous operating systems, different connectivity protocols, and legacy application compatibility [3]. IoT infrastructures (e.g., Sensors, WSN, and RFID) are the specific or pervasive location (things placed everywhere), resource constrained and usually expensive for developing and deploying [45, 46] consequently, IoT infrastructures suffer from inflexibility in terms of resource access and

* Corresponding author

E-mail address: jpourmail@gmail.com

DOI: 10.22105/riej.2018.88380

availability. The IoT devices often suffer from extremely constrained processing and storage resources and a limited energy budget, as they are often battery-powered [16].

Cloud computing has the virtually unlimited capacity belongs to the storage and processing power. Cloud provides the Web-based communications and on-demand platform to access the data and resource uniformly. Cloud infrastructures are the independent or ubiquitous location (resources usable from everywhere) and provide an ease of access to inexpensive resources [34, 38]. Virtualization in cloud is a result of the location-independence feature of the resource infrastructure.

Interconnection between IoT and the cloud is a way to benefit from the scalable and always available resources provided by the cloud computing technology [7, 17, 20, 24, 42]. Convergence of the IoT and the cloud computing technology is motivated by the need of IoT applications to leverage the scalability, availability, and performance of the cloud [31]. This integration simplifies storing and processing of the collected data; allows the use of the same data in multiple services; eases the combination of data from several devices and users and supports user mobility. Several efforts have taken convergence of IoT and cloud in the research community and in the enterprise [14]. One result of this convergence is the ability to send data to the cloud in a scalable and high performance way, managing applications, monitoring, and controlling the data streams. The cloud can provide scalable and stable storage and processing resources and backend resources for the IoT applications. Most IoT applications contain many heterogeneous geographically distributed sensors generating data and need to handle these data. cloud provides the immense distributed storage and computational capacities for IoT applications to perform complex process [35]. In addition, the several IoT services could benefit from a utility-based delivery paradigm of cloud infrastructure, which emphasizes the on-demand establishment and delivery of IoT applications. From a comparative point of view, Table 1 reports the complementary characteristics of cloud and IoT, inspiring the Cloud-based IoT technology.

The rest of this chapter is organized as follows: Section 2 presents Cloud-based IoT platform and details its properties with respect to storage, processing and communication features. The some projects of the implemented Cloud-based IoT platforms have been presented in Section 3. The last section concludes the paper.

Table 1. Complementary characteristics of cloud and IoT.

	Internet of Things	Cloud Computing
Displacement	Pervasive (things placed everywhere)	Ubiquitous (resources are usable from everywhere)
Components	Real word things	Virtual resources
Computational	Limited computational capacities	Virtually unlimited computational capacities
Storage	No storage or limited storage capacities	Virtually unlimited storage capacities
Role of the internet	Internet as a point of convergence	Internet for service delivery
Big Data	Big Data source	Means to manage Big Data

2. Cloud-Based Internet of Things Platform

The difference between cloud-based internet of things and conventional internet of things is the ability to develop, deploy, run, and manage IoT applications online via the cloud [41]. Figure 1 illustrates the main features of the cloud-based IoT platform and architecture and their interaction with the three cloud computing models (i.e. Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Furthermore, Figure 1 specifies networking, interacting, and integrating the things with the cloud.

Cloud computing technology offers a unified service delivery platform for the IoT applications. All devices in IoT connect to a shared resource pool of the cloud to store and retrieve data. This platform enables users to easily collect, access, process, visualize, archive, share, and search the large amounts of sensor data from different applications [29]. The data of sensors can be processed, analyzed, and stored using the computational and storage resources of the cloud. Furthermore, Cloud-based IoT platform allows sharing the sensor resources by different users and applications under flexible usage scenarios and enables sensor devices to handle the specialized processing tasks [29]. This platform is an extended cloud computing for managing sensors that provides sensor devices as a part of IT resources for end users. It offers users the sensor monitoring and controlling services via the web browser [18, 19]. Moreover, cloud eases the data flow between IoT data collection and processing components and enables simple setup and integration of new things, while keeps the low costs for deploying and complex data processing [29].

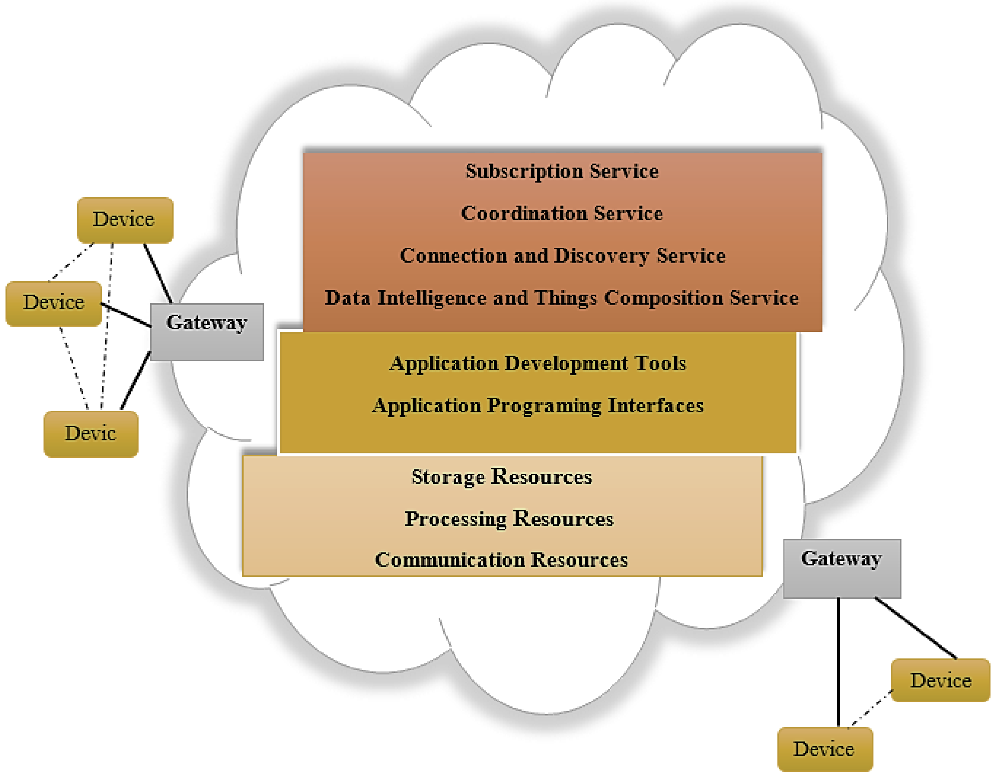

Figure 1. Cloud-based IoT platform.

This platform contains cloud infrastructure, allowing users to run any applications on cloud hardware. The platform simplifies the application development, eliminates the need for infrastructure development, eases things management, and reduces the maintenance costs. It provides users the unique device management capabilities, directly communication with devices, storage to collect data from things, and transition of events. The large amount of sensor data can be stored, processed, and analyzed using the computational and storage resources of cloud. The developer suite is a set of cloud service tools that develops the IoT applications. These tools contain the open web service Application Programming Interfaces (APIs), which provide the high-level development and deployment capabilities to things developers. The operating portal for things is a set of cloud services that support deployment and specialized processing services including subscription management, community coordination, things connection, things discovery, data intelligence, and things composition.

In Cloud-based IoT platform, the IoT devices are typically grouped into one or multiple IoT networks such as a home network or a body area network. These networks are connected to the cloud using a dedicated gateway that can typically be a home router or the user's smartphone. The sensed data in the networks is forwarded to the cloud via the dedicated gateway. The cloud stores the data persistently and makes it accessible to the services and application. The user can authorize particular cloud services to access and operate on her data via the processing resources in cloud [29]. As a result, the cloud acts as an intermediate layer between the things and the IoT applications, where it hides all the complexity and the functionalities of implementation. This platform will influence future application development, where data collecting, data process, and data transmission will produce new challenges to be addressed. Particularly, the design of the Cloud-based IoT platform aims to maximize the availability of data and services [4].

A practical implementation of Cloud-based IoT Platform is shown in Figure 2 that is a smart home application based on cloud [41]. In this platform, the sensors read the home temperature and luminosity from Arduino-enabled IoT things [25] and send data to the cloud platform. Then, the cloud applications store and visualize them so that the user can view, monitor and control them anywhere and anytime using a web browser and an internet connection. In particular, this platform has used LM35 temperature sensor to sense the home environment temperature and a Light Dependent Resistor (LDR) analog sensor to sense the home light luminosity. Moreover, this platform has used Ethernet cable to connect Arduino to the internet and used HTTP to send data between Arduino-enabled IoT things and the cloud applications. Google App Engine as a cloud service has hosted the cloud applications that stores sensor readings and visualizes them. In addition, this platform has utilized a Cloud-based IoT service -Paraimpu- to connect Arduino-enabled sensors and to share the sensor readings with friends.

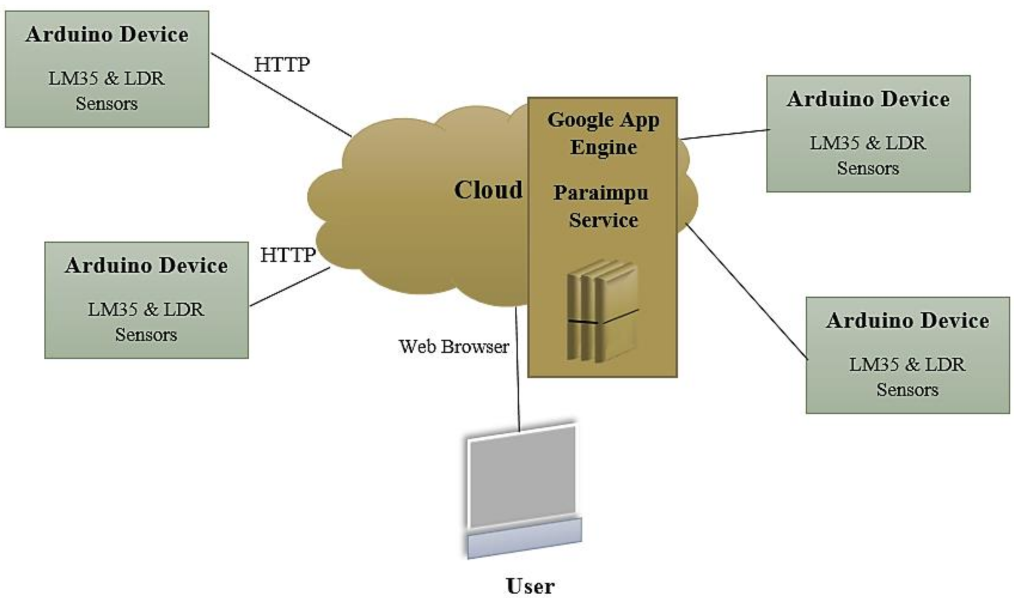

Figure 2. Smart home application based on cloud.

2.1 Managing Sensed Data in Cloud-Based IoT

In order to implement the IoT application properly and managing the massive IoT data in cloud platform (i.e. collecting, storing, processing, and analyzing the sensed data) there are series of issues [21]. The pervasive sensors, RFID readers, and other devices involved in the IoT can generate large volume data rapidly, so that the data must be processed with a high throughput. Since the volume of data is very large and can increase quickly, an efficient data storage solution for the IoT application must be considered to keep the data in an efficient manner. Furthermore, the IoT data are sensed and collected from many diverse sources and are different in data structures, volume, accessing methods, and some other aspects, they can hardly be stored and accessed efficiently by a single method and the data storage components have to be able to deal with the heterogeneous data resources.

2.1.1 Cloud-based IoT storage

Big Data is a collection of complex and large volume datasets that are difficult to process with available database management tools [22, 48]. Big Data can originate from devices of IoT technology such as sensors, RFID readers [5]. As stated by [29], Big Data has three dimensions: volume, variety, and velocity. Volume character refers to large transactions, variety refers to data-types, and velocity refers to structuring of data and making it available for access and delivery. The issues associated with Big Data are collecting, searching, sharing, visualizing, and storing the data by the existing database, and process and analyze the data in order to decision making and control messages generating. Integrating cloud with IoT can provide above requirements. This platform offers virtually unlimited, low-cost, and on-demand storage capacity [29]. Cloud storage is the most convenient and cost effective solution to deal with the produced data by IoT. This integration causes a new convergence scenario [27] where new opportunities become apparent for data aggregation [12], data integration, and sharing data with third parties [39]. In Cloud-based IoT platform, data can be treated in a homogeneous manner through standard APIs, and can be sheltered by applying top-level security, and directly accessed and visualized from any place [29]. Besides, this platform provides the high accessibility and reliability, easy deployment, high protection for data backup, archival and recovery from disaster, and low cost on the whole [32]. Consequently, cloud is in the service of resolving the problems associated with the storage and access of IoT data.

2.1.2 Cloud-based IoT Processing

Issues of this section involve the ways of processing and analyzing the collected and integrated data from multiple sources for identifying the behavior of the actuators to fulfill the need of the application or the service. IoT devices with limited processing resources cannot process data on-site. The collected data are usually transmitted to more powerful nodes for aggregation and process; therefore, the IoT processing model does not provide scalability [4]. The virtualized unlimited processing resources of cloud and its on-demand model provides IoT the scalable process and enables analyzing of unprecedented complexity [6]. Therefore, cloud technology can support the analysis of data generated by sensors and IoT devices. Cloud computing realizes data-driven decision-making and prediction algorithms at low cost, and provides increasing revenues and reduced risks [39]. Besides, the Cloud-based IoT platform allows to perform real-time process (on-the-fly) [6, 29], implement scalable, real-time, collaborative, and sensor-centric applications [12], manage complex events, and implement task offloading for energy saving [37].

2.2 Communication Issues in Cloud-Based IoT

The heterogeneity of hardware and software components in IoT application is high and there are a huge sensors and IoT-devices which gather data in different formats [10]. These aspects can affect the communication mechanism for transferring the sensed data and the actuator control information. As a result, a mechanism must be simple, pluggable, and reliable in order to provide robust communications. One of the requirements of IoT is to link the IP-enabled devices through dedicated hardware. Cloud provides an effective and low cost solution to connect, track, and manage anything from anywhere at any time using the customized portals and built-in apps (i.e. web service interface is provided to submit and retrieve data) [29]. Because of the availability of high-speed networks, cloud enables the monitoring and control of remote things, their coordination and communications, and the real-time access to the produced data [12, 27, 29, 34].

2.2.1 Data interchange format

The sensor and IoT device data formats influence on transport and analyzing methods. This aspect of IoT plays the role of formatting the sensed data into a platform-neutral data interchange format, enabling portability, interoperability, and efficient transportation [9] . The data interchange formats can be classified into two groups [8, 13]: (i) self-describing such as XML and JSON and (ii) binary (schema-based) like Message Pack, XDR, and Protocol Buffers [9]. The two format types have some advantages and drawbacks. Self-describing data interchange format groups are human readable, however, from the transmission view, they include redundant components such as tags, which affect the size of transferred data. Furthermore, the self-describing data are text based formats and therefore add computational overhead and require many bytes to transmit the same data more than the binary format. In addition, because these formats are text based, values must be converted from their native type to a text representation. The binary data interchange format groups are not human readable, however, they are very compact for transmission according to the performance results in [10]. This format provides a standardized mechanism for transmitting data, while minimizes the cost corresponds to the time and volume of encoding the data. There are two categories of messages: Control messages and data messages [41]. A control message consists of command id and key-value pairs specific to that command. These messages are user defined that are implemented by the sensor module or are system control messages that Cloud-based IoT uses these for controlling the behavior of sensors in certain predefined situations. Data messages include huge volume of Cloud-based IoT messages and present the sensor data. Each sensor module generates a uniquely formatted data message with different semantics and the Cloud-based IoT does not infer or act upon the message itself. Furthermore, Cloud-based IoT places messages of any sensor in a general collection and interacts with properties common to all Cloud-based IoT messages such as timestamp.

2.2.2 Interaction protocol

CoAP is a specialized web transfer protocol in Cloud-based IoT for interacting with things [41] that is provided for constrained nodes and constrained networks. This protocol has planned for Machine-to-Machine (M2M) applications such as smart energy and building automation. CoAP is a request/response interaction model between end-points application. This protocol provides built-in discovery of services and resources, contains key concepts of the web such as URIs and internet media types, and meets multicast support and very low overhead [41]. The architecture and interaction model of CoAP is similar to HTTP. In contrast to HTTP, the CoAP message exchange method is based on UDP and is based on an asynchronous way [49].

There are two architectural styles for web services applications: Representational State Transfer (REST) [11, 50, 51] and Service-Oriented Architecture (SOA) [2, 52]. Each of them describes methods to design and develop the interoperable services and designs principles via the web. As stated by [26, 28, 53], SOAs are not well suited for enabling the end-users to create ad-hoc applications and their functional blocks and service implementations are complex. Besides, SOAs are often used to model and realize the complex business flows. The REST style [40] uses HTTP-similar standardized methods (e.g. GET, PUT, POST, DELETE, etc.) to deal with resources as services. Moreover, REST can presents resources by text, JSON, and XML formats.

6LoWPAN (IPv6-based Low Power Wireless Area Networks) protocol [30, 41] provides IP access to a wide set of networked devices with short range and low power constrained hosts. 6LoWPAN as an adaptation layer defines message frame formats, fragmentation methods, and header compression techniques needed to fit Ipv6/UDP datagrams in the very limited IEEE 802.15.4 frame size. This protocol is able to reduce the IPv6/UDP header while keeping the main functionalities and the size of the addressing space, thanks to a cross-layer optimization approach.

Routing Protocol for Low power and lossy networks (RPL) provides routing functionalities [36, 54], which is IETF (Internet Engineering Task Force) solution discussed in the Routing Over Low power and Lossy networks (ROLL) working group. RPL supports distinct routing path optimizations based on particular objective functions such as high priority aspect in which packets with high priority be routed to offer low delivery delay. Another important feature of RPL is its intrinsic scalability in respect of the network density.

2.2.3 Application programming interface

Cloud-based IoT realizes APIs to gain the interoperability. The main APIs are the sensor API and client API [41, 55]. The sensor API is used to register sensor modules with the Cloud-based IoT, publish data, and receive control messages sent by applications or clients. The sensor API enables end-users to define a sensor-specific data format. Sensors connect to Cloud-based IoT and register themselves to it, and then can begin publishing data. A sensor module collects data from a physical sensor or other data sources and submits them to the Cloud-based IoT by the functions provided in the sensor API. The client API consists of some classes needed for registering a client with the Cloud-based IoT and subscribing to sensors of interest by URL. Clients can get information about the sensors that have connected to the system, subscribe to the sensors satisfy the client's criteria with the names or the ID of the mentioned sensors. Besides, clients may also issue sensor-specific control messages to the set of subscribed sensors, and discover them.

3. Cloud-Based IoT Project

In this section, we review the implemented platform that has integrated cloud computing and Internet of Things in details. OpenIoT project (co-funded by the European Commission) has provided a middleware platform for diverse IoT applications based on cloud [31]. OpenIoT offers an adaptable infrastructure for collecting and processing data of sensors and utilizing the Linked Data concept [15] in order to linking the related sensor's data sets. Furthermore, OpenIoT provides functionalities to filter and select data dynamically and deals with mobile sensors. It offers a wide range of visual tools to achieve the development of Cloud-based IoT applications through minimal programming effort.

The OpenIoT architecture consists of seven main elements [32] as depicted in Figure 3:

- Extended Global Sensor Networks (X-GSN) [1] is as sensor middleware that collects, filters, and integrates data from the virtual sensors or physical devices. It plays the role of hub between the OpenIoT platform and the physical world. The sensor middleware includes one or more distributed nodes belong to different administrative entities.
- Linked Stream Middleware Light (LSM-Light) [28] is as cloud data storage that enables storing data originating from the sensor middleware. Furthermore, the cloud infrastructure stores the metadata (functional data) required for the operation of OpenIoT. The OpenIoT uses LSM-Light and cloud interfaces for enabling additional Cloud-based data process.
- The Scheduler processes requests for on-demand services from the Request Definition and provides access to the resources (e.g. data) that they require. The Scheduler allows discovering sensors and associated data belong to a given service. Furthermore, it manages the services and selects/enables the resources participating in service provision.
- Service Delivery & Utility Manager (SD&UM) integrates data as indicated by service workflows within the OpenIoT system in order to deliver the requested service. To this goal, the SD&UM utilizes the service description and resources identified and reserved by the Scheduler. The SD&UM keeps track utility metrics for each service that is needed for driving functionalities such as accounting, billing, and utility-driven resource optimization.
- Request Definition component provides on-the-fly specification of service requested to the OpenIoT platform. It involves a set of services to specify and formulate such requests. Request Definition also submits request to the Scheduler and uses a GUI.

- Request Presentation component is responsible for visualization of the service outputs. This element selects mash-ups from an appropriate library in order to facilitate service presentation and communicates directly with the SD&UM for retrieving the relevant data.
- Configuration and Monitoring component enables visual management and configuration of functionalities over sensors and services implemented in the OpenIoT platform.

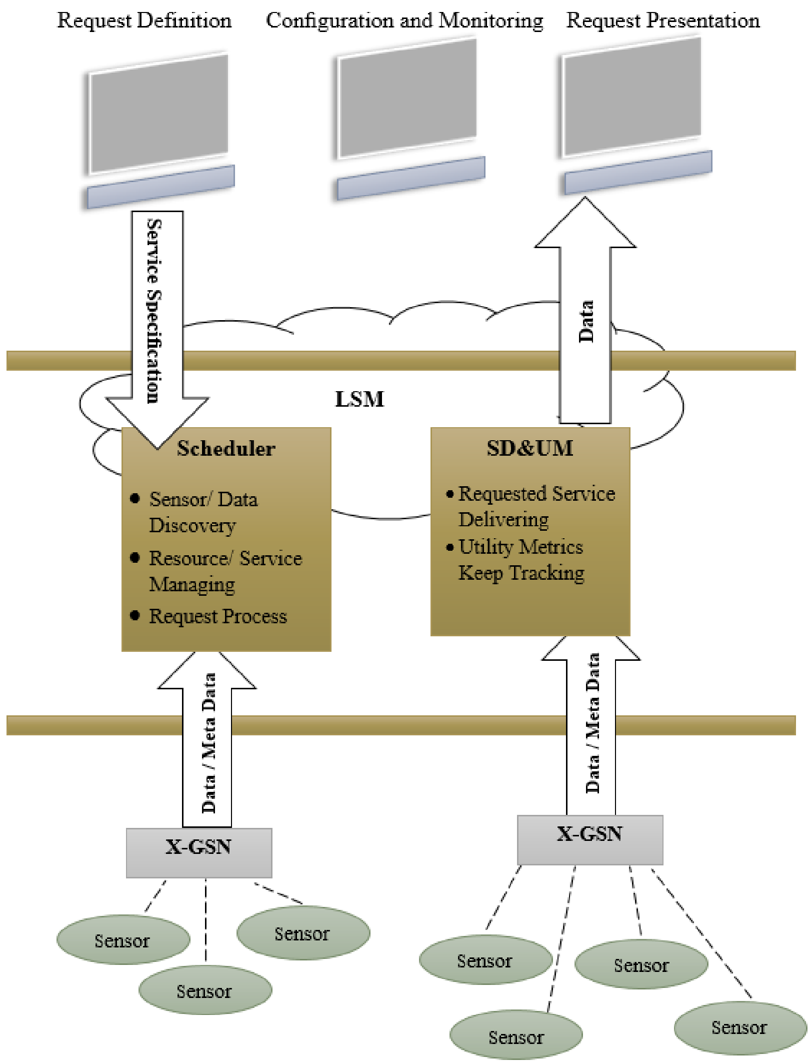

Figure 3. The OpenIoT platform.

4. Conclusion

The Cloud-based IoT has enhanced the performance of IoT technology regards to storage feature, process power, and communication property. Cloud provides the storage components to store the huge volume of sensed data, and offers processing units to analyze them on-the-fly that are transferred through the cloud's communication links and protocols. We presented the integrated platform of IoT and cloud as Cloud-based IoT and described its infrastructure based on the storing, processing, and communication features. Cloud-based IoT influences the data format and the connecting protocols of things, and provides the web service-based communication for them.

References

[1] Aberer, K., Hauswirth, M., & Salehi, A. (2007). Infrastructure for data processing in large-scale interconnected sensor networks. *Proceedings of international conference on mobile data management*. Mannheim, Germany: IEEE.

[2] Erl, Th. (2005). *Service-Oriented Architecture (SOA) concepts, technology and design*. New Jersey, NJ: Prentice Hall PTR Upper Saddle River.

[3] Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: a survey. *Computer networks*, *54*(15), 2787-2805.

[4] Botta, A., Donato, W., Persico, V & Pescapé, A. (2014). On the Integration of cloud computing and internet of things. *Proceedings of the international conference on future internet of things and cloud (FiCloud).* Barcelona, Spain: IEEE.

[5] Bryant, R., Katz, R. H., & Lazowska, E. D. (2008). *Big-data computing: creating revolutionary breakthroughs in commerce, science and society*. Retrieved June 18, 2019 from https://www.immagic.com/eLibrary/ARCHIVES/GENERAL/CRA_US/C081222B.pdf

[6] Dash, S. K., Mohapatra, S., & Pattnaik, P. K. (2010). A survey on applications of wireless sensor network using cloud computing. *International journal of computer science & engineering technologies*, *1*(4), 50-55.

[7] Eggert, M., Häußling, R., Henze, M., Hermerschmidt, L., Hummen, R., Kerpen, D., . . . Wehrle, K. (2014). SensorCloud: Towards the interdisciplinary development of a trustworthy platform for globally interconnected sensors and actuators. In H. Krcmar, R. Reussner & B. Rumpe (Eds.), *trusted cloud computing* (pp. 203-218). Springer, champ.

[8] Eisler, M. (2006). *XDR: External data representation standard*. Retrieved from https://www.rfc-editor.org/rfc/pdfrfc/rfc4506.txt.pdf

[9] Emeakaroha, V. C., Cafferkey, N., Healy, P., & Morrison, J. P. (2015a). A cloud-based iot data gathering and processing platform. *Proceedings of 3rd international conference on the future internet of things and cloud (FiCloud)*. Rome, Italy: IEEE.

[10] Emeakaroha, V. C., Fatema, K., Healy, P., & Morrison, J. P. (2015b). Contemporary analysis and architecture for a generic cloud-based sensor data management platform. *Sensors & Transducers*, *185*(2), 100.

[11] Fielding, R. T., & Taylor, R. N. (2000). *Architectural styles and the design of network-based software architectures* (Doctoral dissertation: University of California, Irvine).

[12] Fox, G. C., Kamburugamuve, S., & Hartman, R. D. (2012). Architecture and measured characteristics of a cloud based internet of things. *Proceedings of the international conference on collaboration technologies and systems (CTS)*(pp. 6-12). Denver, CO: USA.

[13] Gil, B., & Trezentos, P. (2011). Impacts of data interchange formats on energy consumption and performance in smartphones. *Proceedings of the 2011 workshop on open source and design of communication* (pp. 1-6). New York, NY.

[14] Hassan, M. M., Song, B., & Huh, E.-N. (2009). A framework of sensor-cloud integration opportunities and challenges. *Proceedings of the 3rd international conference on ubiquitous information management and communication*. New York, NY: ACM.

[15] Heath, T. (2011). Linked data-welcome to the data network. *IEEE internet computing*, *15*(6), 70-73.

[16] Henze, M., Hermerschmidt, L., Kerpen, D., Häußling, R., Rumpe, B., & Wehrle, K. (2016). A comprehensive approach to privacy in the cloud-based Internet of Things. *Future generation computer systems*, *56*, 701-718.

[17] Henze, M., Hummen, R., Matzutt, R., Catrein, D., & Wehrle, K. (2013). Maintaining user control while storing and processing sensor data in the cloud. *International journal of grid and high performance computing* (IJGHPC), *5*(4), 97-112.

[18] Henze, M., Hummen, R., Matzutt, R., & Wehrle, K. (2014). A trust point-based security architecture for sensor data in the cloud. In H. Krcmar, R. Reussner & B. Rumpe (Eds.), *Trusted cloud computing* (pp. 77-106). Springer International Publishing.

[19] Hermerschmidt, L., Perez, A. N., & Rumpe, B. (2014). A model-based software development kit for the sensorcloud platform. In H. Krcmar, R. Reussner & B. Rumpe (Eds.), *Trusted cloud computing* (pp. 125-140). Springer International Publishing.

[20] Hummen, R., Henze, M., Catrein, D., & Wehrle, K. (2012). A Cloud design for user-controlled storage and processing of sensor data. *Proceedings of the 4th international conference on cloud computing technology and science* (CloudCom). Taipei, Taiwan: IEEE.

[21] Jiang, L., Da Xu, L., Cai, H., Jiang, Z., Bu, F., & Xu, B. (2014). An IoT-oriented data storage framework in cloud computing platform. *IEEE transactions on industrial informatics*, *10*(2), 1443-1451.

[22] Labrinidis, A., & Jagadish, H. (2012). Challenges and opportunities with big data. *Proceedings of the VLDB endowment*, *5*(12), 2032-2033.

[23] Le-Phuoc, D., Nguyen-Mau, H. Q., Parreira, J. X., & Hauswirth, M. (2012). A middleware framework for scalable management of linked streams. *Web semantics: science, services and agents on the World Wide Web*, *16*, 42-51.

[24] Li, F., Vögler, M., Claeßens, M., & Dustdar, S. (2013). Efficient and scalable IoT service delivery on cloud. *Proceedings of the sixth international conference on cloud computing*. Santa Clara, CA: IEEE.

[25] Melgar, E. R., & Diez, C. C. (2012). *Arduino and kinect projects: design, build, blow their minds*. Apress.

[26] Moritz, G., Golatowski, F., Lerche, C., & Timmermann, D. (2013). Beyond 6LoWPAN: Web services in wireless sensor networks. *IEEE transactions on industrial informatics*, *9*(4), 1795-1805.

[27] Parwekar, P. (2011). From internet of things towards cloud of things. *Proceedings of 2nd international conference on computer and communication technology (ICCCT-2011)*(pp. 329-333). Allahabad, India: IEEE.

[28] Pintus, A., Carboni, D., & Piras, A. (2011). The anatomy of a large scale social web for internet enabled objects. *Proceedings of the second international workshop on web of things*. New York, NY.

[29] Rao, B., Saluia, P., Sharma, N., Mittal, A., & Sharma, S. (2012). Cloud computing for internet of things & sensing based applications. *Proceedings of the sixth international conference on sensing technology* (ICST). Kolkata, india: IEEE.

[30] Shelby, Z., & Bormann, C. (2011). *6LoWPAN: The wireless embedded internet*. Wiley Publishing.

[31] Soldatos, J., Kefalakis, N., Hauswirth, M., Serrano, M., Calbimonte, J.-P., Riahi, M., . . . Žarko, I. P. (2015). Openiot: open source internet-of-things in the Cloud. In I. P. Žarko, K. Pripužić & M. Serrano (Eds), *Interoperability and open-source solutions for the internet of things* (pp. 13-25). Springer.

[32] Soldatos, J., Kefalakis, N., Serrano, M., & Hauswirth, M. (2014). Design principles for utility-driven services and cloud-based computing modelling for the internet of Things. *International journal of web and grid services 6*, *10*(2-3), 139-167.

[33] Srivastava, P., & Garg, N. (2015). Secure and optimized data storage for IoT through cloud framework. *Proceedings of the international conference on computing, communication & automation (ICCCA)*, Noida, India: IEEE.

[34] Suciu, G., Fratu, O., Halunga, S., Cernat, C. G., Poenaru, V., & Suciu, V. (2011). Cloud consulting: ERP and communication application integration in open source cloud systems. *Proceedings of the 19th telecommunications forum* (TELFOR). Belgrade, Serbia: IEEE.

[35] Suciu, G., Vulpe, A., Halunga, S., Fratu, O., Todoran, G., & Suciu, V. (2013). Smart cities built on resilient cloud computing and secure internet of Things. *Proceedings of the 19th international conference on control systems and computer science* (CSCS). Bucharest, Romania: IEEE.

[36] Winter, T., Thubert, P., Brandt, A., Hui, J., Kelsey, R., Levis, P., ... & Alexander, R. (2012). *RPL: IPv6 routing protocol for low power and lossy networks.* Retrieved from https://tools.ietf.org/html/rfc6550.

[37] Yao, D., Yu, C., Jin, H., & Zhou, J. (2013). Energy efficient task scheduling in mobile cloud computing. In Ch-H. Hsu, X. Li, X. Shi & R. Zheng (Eds.), *Network and parallel computing* (pp. 344-355). Springer.

[38] Zainea, E., Martian, A., Marcu, I., & Fratu, O. (2012). Transition from analog to digital broadcasting: a spectral efficiency review. *Proceedings of the 10th international symposium on electronics and telecommunications* (ISETC). Timisoara, Romania: IEEE.

[39] Zaslavsky, A., Perera, C., & Georgakopoulos, D. (2013). Sensing as a service and big data. *Proceedings of international conference on advances in cloud computing (ACC)*(pp.21-29). Bangalore, India

[40] Zhao, H., & Doshi, P. (2009). Towards automated restful web service composition. *Proceedings of the IEEE International Conference on Web Services (ICWS)*. Los Angeles, CA: IEEE.

[41] Zhou, J., Leppanen, T., Harjula, E., Ylianttila, M., Ojala, T., Yu, C., . . . Yang, L. T. (2013). CloudThings: a common architecture for integrating the internet of things with cloud computing. *Proceedings of the 17th international conference on computer supported cooperative work in design* (CSCWD). Whistler, BC: IEEE.

[42] Knaack, Z. (2017). Internet of things. *Technology and engineering Teacher, 76(6),* 28.

[43] Stojkoska, B. L. R., & Trivodaliev, K. V. (2017). A review of internet of things for smart home: challenges and solutions. *Journal of cleaner production*, *140*, 1454-1464.

[44] Chen, E. T. (2017). The internet of things: opportunities, issues, and challenges. *The Internet of Things in the Modern Business Environment* (pp. 167-187). IGI Global.

[45] Garulli, N., Boni, A., Caselli, M., Magnanini, A., & Tonelli, M. (2017, September). A low power temperature sensor for IOT applications in CMOS 65nm technology. *Proceedings of 2017 IEEE 7th international conference on consumer electronics-berlin (ICCE-Berlin)* (pp. 92-96). Berlin, Germany: IEEE.

[46] Botta, A., De Donato, W., Persico, V., & Pescapé, A. (2016). Integration of cloud computing and internet of things: a survey. *Future generation computer systems*, *56*, 684-700.

[47] Stergiou, C., Psannis, K. E., Kim, B. G., & Gupta, B. (2018). Secure integration of IoT and cloud computing. *Future generation computer systems*, *78*, 964-975.

[48] Maass, W., Parsons, J., Purao, S., Rosales, A., Storey, V. C., & Woo, C. C. (2017). Big Data and Theory. *Encyclopedia of big data*, 1-5.

[49] Kovatsch, M., Lanter, M., & Shelby, Z. (2014). Californium: Scalable cloud services for the internet of things with coap. *2014 international conference on the internet of things (IOT)* (pp. 1-6). IEEE.

[50] Pautasso, C. (2014). RESTful web services: principles, patterns, emerging technologies. In *Web services foundations* (pp. 31-51). Springer, New York, NY.

[51] Maleshkova, M., Pedrinaci, C., & Domingue, J. (2010). Investigating web apis on the world wide web. *2010 eighth ieee european conference on web services* (pp. 107-114). IEEE.

[52] Erl, T. (2016). *Service-oriented architecture: analysis and design for services and microservices*. Prentice Hall Press.

[53] Pautasso, C., Zimmermann, O., & Leymann, F. (2008). Restful web services vs. big'web services: making the right architectural decision. *Proceedings of the 17th international conference on World Wide Web* (pp. 805-814). ACM.

[54] Tripathi, J., de Oliveira, J. C., & Vasseur, J. P. (2010, March). A performance evaluation study of rpl: Routing protocol for low power and lossy networks. *2010 44th annual conference on information sciences and systems (CISS)* (pp. 1-6). IEEE.

[55] Hou, L., Zhao, S., Li, X., Chatzimisios, P., & Zheng, K. (2017). Design and implementation of application programming interface for Internet of things cloud. *International journal of network management*, *27*(3), e1936.