IoT Cloud Platforms: an Application Development Perspective

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Abstract— With the growing number of Internet of Things (IoT) devices, the data generated through these devices is also growing. By 2025, it has been predicted that the number of IoT devices will exceed the number of human beings on earth. Thus, the data generated through these IoT devices will be gigantic. This gives upsurge in storage. One of the most promising solutions is to store data on cloud. Market is overhelming with the number of IoT cloud platforms. In spite of availability of huge variety of IoT cloud platforms, very little attempt in classifying or comparing it for the applications to be developed is found across the literature databases. This paper categorizes IoT platforms into four categories namely: publicly traded, open source, developer friendly and end to end connectivity. Some of the popular platforms in each category are identified and compared based on the given general IoT architecture. This study can be useful for newbies and application developers in IoT to select the most appropriate platform according to requirement for building applications.

Keywords— IoT; Cloud; Analytics; IoT Cloud Platforms.

I. INTRODUCTION (Heading 1)

The advancement in sensor, actuator, computing and storage technologies has given rise to era of ‘Internet of Things’ (IoT). The emergence of smaller and cheaper interoperable wireless devices over low powered wireless medium has made the communication among these devices and human possible. These wireless devices can foster development of many smart applications in various domains such as smart home, smart traffic, smart healthcare, smart city, smart agriculture, smart logistics etc.[1]

IoT devices sense the surroundings. If large number of IoT devices is connected, then they are going to sense large number of events generating massive data. This data can be either structured, unstructured and semi structured. The data can be generated at constant rate or time triggered. For analysis of such kind of data, it is essential to be stored resourcefully. Cloud is one of the possible solutions. Different IoT vendors worldwide are coming with different IoT cloud platforms to support this requirement. Broadly IoT platforms can be divided into following four broad categories [2]: Publicly Traded, Open Source, Developer Friendly and End to End Connectivity platforms.

II. GENERAL ARCHITECTURE OF IOT CLOUD PLATFORM

This section describes the basic elements of IoT Cloud Platform reference architecture [3]. All elements of this architecture are described in the bottom up manner as shown in fig 1.

A. Sensors

Sensor consists of a hardware component capable of acquiring information about physical environment. This acquired information is transmitted in form of electrical signals to the connected devices. Devices connectivity can be either wired or wireless.

B. Actuator

It is a hardware component which receives command in form of electrical signals from connected device and performs some kind of physical action. Like sensor, it can also be connected to device either in a wired or wireless manner.

C. Device

A Device is a hardware component consisting of processor and storage. It is connected to sensors and actuators. By the help of software, it can establish connection to IoT Integration middleware.

D. Gateway

Sometimes gateway is required to connect device to IoT platform. Gateway is an interface that provides technologies and mechanism to interconnect between communication technologies and protocols. All devices can access gateway if they are IP enabled. Gateway is also able to store, filter and process received data before sending to cloud.
E. IoT Cloud Platform

Main responsibilities of this layer are:

1. It integrates data received from different kind of connected devices.
2. Process the received data.
3. Control devices
4. Provide received data to various applications.

IoT cloud Platform can also directly communicate with device if both are using compatible technologies and protocols.

IoT Cloud Platform layer is also responsible for providing functionalities such as time series database or graphical dashboards, aggregation and utilization of data received from devices. Mostly, IoT platforms are accessed through HTTP-based REST APIs.

F. Application

Applications are built on top of various IoT Cloud Platforms to provide services to some real-life scenario.

III. DIFFERENT IOT CLOUD PLATFORM

Various IoT Cloud platforms can be categorized into following four categories namely Public Traded IoT Cloud Platforms, Open Source IoT Cloud Platforms, Developer Friendly IoT Cloud platform, End to End connectivity IoT cloud Platform as shown in fig 2. below. This section describes various popular platforms in each of these categories:

A. Publicly Traded IoT Cloud Platforms

This category consists of platforms developed and maintained by large public traded companies such as AWS IoT Platform[4], Microsoft Azure IoT Hub[5], IBM Watson IoT Platform[6], Google IoT Platform[7], Oracle IoT Platform[8].

B. Open source IoT Cloud Platforms

This category consists of platforms that provide data management services under open licenses such as Kaa[9], ThingSpeak[10].

C. Developer Friendly IoT Cloud Platform

This category of platforms is developer friendly. They can be easily integrated with Arduino, Raspberry etc. to develop users’ applications such as Carriots[11], Temboo[12].

D. End to End Connectivity IoT Cloud Platform

Platforms designed based on supplied hardware and required solution such as Samsara[13], Particle Cloud[14].

IoT Cloud Platforms are summarized in various tables. We have used “Y” in tables to show support of certain feature and absence of Y shows lack of support. The Basic feature of IoT Cloud Platforms are summarized in TABLE 1. In this table we have considered parameters namely Open source or open API, deployment model of cloud, availability, data format supported, programming languages supported and pricing model of platforms.
### TABLE I. BASIC FEATURES OF IOT CLOUD PLATFORMS

| IoT Cloud Platform          | Open Source/Open SDK | Deployment type | Availability (24*7) | Data Format Supported | Programming Languages Support | Pricing                                      |
|-----------------------------|----------------------|-----------------|--------------------|-----------------------|-------------------------------|---------------------------------------------|
| AWS IoT Platform            | Open source SDK      | PaaS, IaaS      | Y                  | JSON                  | Java, C, NodeJS, Javascript, Python, SDK for Arduino, iOS, Android | Pay when execute your own written functions. |
| Microsoft Azure IoT Hub     | Open Source API      | IaaS            | Y                  | JSON                  | .NET, UWP, Java, C, NodeJS, Ruby, Android, iOS | Pay according to number of devices and messages per day |
| IBM Watson IoT Platform     | Open source SDK      | PaaS, IaaS      | Y                  | JSON, CSV             | C#, C, Python, Java, NodeJS   | Pay according to number of devices, data traffic and data storage |
| Google IoT Platform         | Open API             | PaaS, IaaS      | Y                  | JSON                  | Go, Java, .NET, Node.js, php, Python, Ruby | Priced per MB |
| Oracle IoT Platform         | Open source SDK      | PaaS            | Y                  | CSV, REST API         | Java, Javascript, Android, C, iOS | Subscription based |

| Kaa                         | Open SDK             | IaaS            | REST API, JSON, ThingSpeak API, JSON, XML | Java, C, C++ | Free |
| ThingSpeak                  | Open source API      | PaaS            | Excel, CSV, XML, JSON | Matlab | Free |

**SENSING FEATURES OF IOT CLOUD PLATFORM**

| IoT Cloud Platform          | Multi Device Support | Heterogeneous Device Support | Hardware Compatibility |
|-----------------------------|----------------------|-----------------------------|------------------------|
| PUBLICLY TRADED IOT CLOUD PLATFORM |                      |                             | Broadcom, Marvell, Renasas, Texas Instruments, Microchip Intel |

**TABLE II. SENSING FEATURES OF IOT CLOUD PLATFORM**

| IoT Cloud Platform          | Multi Device Support | Heterogeneous Device Support | Hardware Compatibility |
|-----------------------------|----------------------|-----------------------------|------------------------|
| AWS IoT Platform            | Y                    | Y                           | Broadcom, Marvell, Renasas, Texas Instruments, Microchip Intel |
| IoT Cloud Platform         | Gateway | Protocols                  | Security               | Scope for user defined policies |
|----------------------------|---------|----------------------------|------------------------|---------------------------------|
|                            |         |                            | Encryption | Authentication | Authorization | Auditing |                                  |
| **Publicly Traded IoT Cloud Platforms** |         |                            | Y          | Y             | Y            | Y        |                                  |
| AWS IoT Platform            | Y       | HTTP, MQTT, Websockets     | Y          | Y             | Y            | Y        |                                  |
| Microsoft Azure IoT Hub     | Y       | HTTP, AMQP, HTTPS          | Y          | Y             | Y            |          |                                  |
| IBM Watson IoT Platform     | Y       | MQTT                       | Y          | Y             |              |          |                                  |
| Google IoT Platform         |         | MQTT, HTTP                 | Y          |              |              |          |                                  |
| Oracle IoT Platform         | Y       | REST APIs                  | Y          | Y             |              |          |                                  |
| **Open Source IoT Cloud Platforms** |         |                            | Y          | Y             | Y            |          |                                  |
| Kaa                        | Y       | MQTT, CoAP                 | Y          |              |              |          |                                  |
| ThingSpeak                 |         | MQTT                       | Y          |              |              |          |                                  |
| **Developer Friendly IoT Cloud Platforms** |         |                            | Y          |              |              |          |                                  |
The support for various application development technologies is given in TABLE IV. In this table we have discussed technologies used in various IoT cloud platforms and parameters such as M2M applications, real time analytics, machine learning, artificial intelligence, analytics, visualization, and event reporting. “Y” shows support for particular features.

### TABLE IV. APPLICATION DEVELOPMENT SUPPORT FEATURES IN IOT CLOUD PLATFORM

| IoT Cloud Platform          | Support for Application Development | Technologies Used                                                                 |
|-----------------------------|--------------------------------------|-----------------------------------------------------------------------------------|
|                             | M2M application                      | Real Time Analytics | Machine Learning | Artificial Intelligence | Analytics | Visualization | Event and Reporting |
| Publicly Traded IoT Cloud Platform |                                     |                                                |                           |                |                      |                      | AWS Lambda, Amazon Kenisis, Amazon Machine learning, Amazon Dynamo DB, Amazon CloudWatch, AWS CloudTrail, |
| AWS IoT Platform            | Y                                    | Y                                               | Y                          | Y                 | Y                     | Y                     |                                                                         |
| Microsoft Azure IoT Hub     | Y                                    | Y                                               | Y                          | Y                 | Y                     | Y                     | Azure CosmosDB, Azure Tables, SQL database                              |
| IBM Watson IoT Platform     | Y                                    |                                                 | Y                          | Y                 | Y                     | Y                     | Cloudant NOSQL DB                                                      |
| Google IoT Platform         | Y                                    |                                                 | Y                          | Y                 | Y                     | Y                     | Google's BigData tool, Riptide IO, BigQuery, Firebase, PubSub           |
| Oracle IoT Platform         | Y                                    |                                                 | Y                          | Y                 | Y                     | Y                     | NoSQL Database                                                         |
| Open Source IoT Cloud Platform |                                     |                                                |                           |                |                      |                      | NoSQL, Cassandra, Hadoop and MongoDB                                   |
| Kaa                         | Y                                    |                                                 | Y                          | Y                 | Y                     |                      |                                                                         |
| ThingSpeak                  | Y                                    |                                                 | Y                          | Y                 | Y                     |                      | Matlab, dashboard                                                      |
| Developer Friendly IoT Cloud Platform |                                     |                                                |                           |                |                      |                      |                                                                         |
| Carriots                    | Y                                    |                                                 | Y                          | Y                 |                      |                      | NoSQL BigDatabase                                                     |
| Temboo                      | Y                                    |                                                 | Y                          | Y                 |                      |                      | Microsoft Power BI, Google BigQuery                                    |
| End-to-End Connectivity IoT Cloud Platform |                                     |                                                |                           |                |                      |                      |                                                                         |
| Samsara                     |                                      |                                                 | Y                          | Y                 |                      |                      |                                                                         |
| Particle Cloud              |                                      |                                                 | Y                          | Y                 |                      |                      | IFTTT                                                                   |
IV. DISCUSSIONS

In this paper we have discussed the basic features, sensing features, communication features, and support for application development features. This information can help IoT application developers in selecting appropriate platforms according to their application need. In basic features support for open source/open sdk/open API, cloud deployment model used, availability, data format supported, programming languages supported and pricing model of various platforms in each category are discussed. Sensing features i.e. capability to sense information from multi devices, heterogeneous devices, compatibility with hardware is given. In communication features support for gateways, different protocols supported, security features such as encryption, authorization, authentication and provision for extension of security policy according to application is presented. Lastly, we discussed support of tools for application development. Different applications require different kind of tools. This can help application developers in choosing platform according to tools required in their application.

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