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A survey of IoT cloud platforms

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Abstract

Internet of Things (IoT) envisages overall merging of several “things” while utilizing internet as the backbone of the communication system to establish a smart interaction between people and surrounding objects. Cloud, being the crucial component of IoT, provides valuable application specific services in many application domains. A number of IoT cloud providers are currently emerging into the market to leverage suitable and specific IoT based services. In spite of huge possible involvement of these IoT clouds, no standard cum comparative analytical study has been found across the literature databases. This article surveys popular IoT cloud platforms in light of solving several service domains such as application development, device management, system management, heterogeneity management, data management, tools for analysis, deployment, monitoring, visualization, and research. A comparison is presented for overall dissemination of IoT clouds according to their applicability. Further, few challenges are also described that the researchers should take on in near future. Ultimately, the goal of this article is to provide detailed knowledge about the existing IoT cloud service providers and their pros and cons in concrete form.

Keywords: IoT; Cloud; Platform

1. Introduction

The exponential growth in semiconductor domain has resulted in an explosion of usage patterns of cost effective sensor based processor system. These systems when get empowered with advanced communication technologies (e.g., Bluetooth Low Energy, LoRA [7], ZigBee, Insteon, 3G, 4G, 5G etc.) converges into an emerging form of technological domain-Internet of Things or in short IoT. IoT aims to offer, a massive scale, heterogeneous, interoperable, and context aware, and simplified application development cum deployment capabilities to the enterprises and end-users.

According to profitbricks.com, there are at least 49 IoT cloud platforms exist in today's global market to meet the requirements of different user and application groups such as enterprises, government, farmer, healthcare, communication, transportation, and manufacturing [1]. But lack of overall knowledge about these IoT cloud platforms restricts researchers and enthusiasts to choose a particular cloud when they are in phase with development of any product or solution utilizing IoT enabled technologies.

Several articles [15–23] are found that develop and apply IoT solutions based on the existing clouds that are matter of study in this paper. Strong need for integration of cloud and IoT is mentioned in Ref. [24] where an agent-oriented and cloud assisted paradigm is envisaged based on a novel reference architecture. After analyzing various depicted papers, a generic architecture is presented in Ref. [25] where an IoT supported cloud-based smart device is evaluated to perform data monitoring, gathering and processing. A brief survey of the state-of-the-art in sensing services over cloud-centric IoT, and recent challenges are mentioned aiming at defining taxonomy of the stated surveyed schemes in Ref. [26]. *CloudIoT* platform [27] is proposed while highlighting the complementarily and the need for the integration of cloud and IoT together. Based on the results obtained from survey of the measurement for the wine

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growing season during 2014, an M2M (Machine-to-Machine) remote telemetry station in cooperation with a big data processing platform and several sensors is implemented to demonstrate the use of IoT cloud systems and Big Data processing in order to implement disease prediction and alerting application for viticulture [28]. Wang et al. [29] describes various notions (i.e., Datacenter Cloud Computing Infrastructure Service Stack, Data Management Service across Datacenters, Data-Intensive Workflow Computing, Benchmark, Application Kernels, Standards, and Recommendations etc.) to visualize how distributed IoT data could be processed in the clouds. An IoT based Software Defined Radio (SDR) enabled cloud computing paradigm is implemented to provide a unified view on accessing, configuring and operating of the IoT cloud systems while implying dynamic and on-demand service frameworks [30,31] propose the U-GovOps – a novel framework for dynamic, on-demand governance of elastic IoT cloud systems under uncertainty while introducing a declarative policy language to simplify the development of uncertainty- and elasticity-aware governance strategies. 7 different principles of engineering IoT cloud systems are prescribed so as to comprehend and provide knowledge about how IoT cloud systems could provide a coherent software layer for continuous deployment, provisioning, and execution of applications for various domains [32]. An IoT cloud framework is designed to harmonize cloud-scale IoT services defining intention of user or device to enable communication between connected devices in cloud-scale IoT services [33,34] discusses the prospective evolution of IoT Clouds towards federated ecosystems, where IoT cloud systems cooperate to offer more flexible services by proposing a 3-layered federated IoT architecture. A framework is proposed for scalable and real-time provisioning of IoT cloud based services in smart cities. These two features have been achieved by employing a novel hierarchical model and populating them in a tree structure containing references to services and their real-time data [35]. Agent based IoT cloud computing is also provisioned to support the development of decentralized, dynamic, and cooperating open IoT cloud systems incorporating multiple IoT agents [36]. Every paper mentioned in this section is unique in its own way and serve a specific job but none of these do cater the comparison of existing commercial IoT cloud systems.

IoT may be defined as "A global infrastructure for the information society enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies" [37]. The definition of "Cloud" is presented as prescribed by the NIST (National Institute of Standards and Technology) in its Special Publication of 7 pages (800-1457) in September, 2011. According to it, "Cloud Computing is a model for enabling ubiquitous, 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". Till date no definition of IoT cloud was present. Henceforth, the novel definition of IoT Cloud may be framed as "A model designed to facilitate the information society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies through ennoblement of ubiquitous, 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 that leverage the need and heterogeneous connectivity issues of the user centric things in well defined fashion". Here, at this point we may integrate the recently proposed definition of IoT cloud with the cloud platform which is given as "a platform offered by a service provider as a hosted service which facilitates the deployment of software applications without the cost and complexity of acquiring and managing the underlying hardware and software layers [38]." Now finally, IoT cloud platform may be formulated by the novel definition as proposed as: "a platform offered by a service provider as a hosted service which facilitates the deployment of software applications without the cost and complexity of acquiring and managing the underlying hardware and software layers to hinder a model designed to facilitate the information society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies through ennoblement of ubiquitous, 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 that leverage the need and heterogeneous connectivity issues of the user centric things in well defined fashion".

Methodologically, in this survey, 26 different genres of IoT cloud are selected as an arbitrary way to provide information to the readers regarding their technology, specificity, appropriateness, and convergence with existing knowledge of communication platforms. Moreover, these IoT cloud platforms are surveyed according to their appropriate deployment services including application development, device management, system management, heterogeneity management, data management, tools for analysis, deployment, monitoring, visualization, and research (see Fig. 1). While describing the cloud platforms following parameters such as real time data capture capability, data visualization, cloud model type, data analytics, device configuration, API protocols, and usage cost are chosen as the key selective features. The presented article shall pave the readers to gain an intrusive and overall idea about the stringent aspects of the IoT clouds towards solving multiple genres of service domains.

This paper is organized as follow. Section 2 presents acute problems associated with the presented IoT clouds which need to be solved by the researcher while incorporating the enterprises together. Section 3 concludes this paper.

2. Domain specific survey of IoT cloud platforms

This section presents 26 IoT cloud platforms according to their appropriateness into the specific application domains. It is

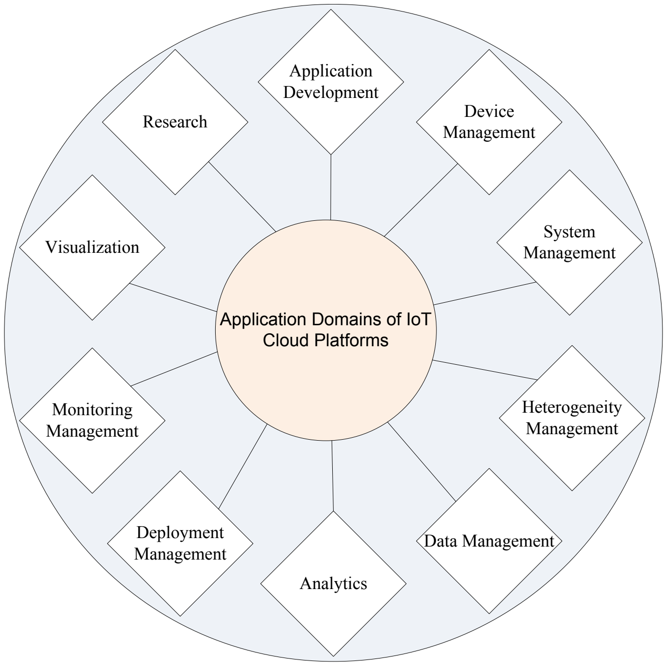

Fig. 1. Application domains of IoT cloud platforms.

obvious that there are many more platforms present in the market, but due to tech-specific and time limits 26 of these are chosen to provide a precise ideas about how they work, what are their strengths, what are their weaknesses, in which domain they are appropriate. While, studying these IoT platforms, each of these was tested in reality to disseminate their strengths and weaknesses. Further, based on applicability and suitability preferences in several domains the IoT cloud platforms have been revisited. 10 different domains are selected based on which most of IoT cloud platforms are currently evolving into the IT market. Management wise few technological sectors are envisioned where these platforms do best fit into such as: Device, System, Heterogeneity, Data, Deployment, and Monitoring. Similarly, Analytics, Research and Visualization fields are chosen where rest of the platforms may be accommodated. While describing the selected cloud platforms following parameters such as real time data capture capability, data visualization, cloud model type, data analytics, device configuration, API protocols, and usage cost are chosen as the key selective features. This section also provides Table 1 that compares IoT clouds according to their suitability and appropriateness in the prescribed division of application domains.

1) Application development

Following platforms are proficient enough to be rigorously used for development and providing solutions to sensor cum actuator vetted problems.

2.1. KAA

KAA (http://www.kaaproject.org/) is an open source multipurpose middleware IoT platform (Apache License 2.0) for building smart, connected and end-to-end IoT solutions. It facilitates data exchange among the attached devices, data analytics, visualization, and IoT cloud services. Capturing of device specifications, performing device provisioning, configuration, enabling cross device communication, and allowing distributed firmware update are the core activities done by KAA. It provides back end functionality to operate large scale IoT solutions comprising data security, consistency, interoperability, and data management with help of SDK that gets embedded into developer's chip or device. KAA SDK requires low memory footprint as minimum as 10 KB RAM and 40 KB ROM. SDK collects data end points, delivers configuration profiles, and enables messaging across end-points. Data storage is done by two options of NoSQL [9] data bases such as, Cassandra, Hadoop [10] and MongoDB.

Pros: NoSQL and Big Data base applications supported.
Cons: Less hardware modules supported.

2.2. Carriots

Carriots (https://carriots.com) is the spin-off of Wairbut (www.wairbut.com) envisages helping anyone to build applications for the IoT very quickly, by saving time, costs and troubles. Platform as a Service (PasS) cloud model is featured with key technicalities such as, remote device management and control, rule based listeners' activity logging, triggering custom alarms, and data export. RESTful API enable the captured data to get derived into Device, Asset, Group, Service, Project, Stream, Rule, Alarm, Listener, Trigger, Networking, Entity and *ConfigTrigger* classes. Email, SMS, Twitter, basic HTTP utility classes to inform user about the current valued situation of devices. Data are stored in NoSQL Big Data Base which extends the big data applicability in true sense.

Pros: Triggering based applications are supported.
Cons: Less user friendly design.

2.3. Temboo

Temboo (https://temboo.com) is a private cloud based application code generation platform. It reduces the overhead of wiring and coding of hardware and software, resulting less time to develop and commercialize an IoT product into the market. More than 90 inbuilt libraries called "Choreos" for third party services indulge user to experience specific services which includes Yahoo weather, Amazon cloud, Ebay product shopping, Flickr photo management, Facebook Graph API, Google analytics, Twitter micro blogging, Twilio telephony, PayPal payment, Uber vehicle confirmation, YouTube video streaming, and many more. Labs [3] is a directory of experimental Choreos that chains many Choreos together, creating powerful workflows that cover a lot of ground on vast live applications and private location aware implementations. It helps developer to visually configure hardware to trigger and response to online processes, save inputs to conserve RAM,

Table 1
Application domain specific IoT clouds.

IoT cloud platforms	Domains									
	Application development	Device management	System management	Heterogeneity management	Data management	Analytics	Deployment Management	Monitoring management	Visualization	Research
Aer cloud			√			√		+		
Arkessa		√			+					
Arrayant connect	√	√		+	√					
Axeda		√			+			√		
Ayla's cloud fabric		√	+						√	
Carriots	+	√						√		
Echelon	√	√					+			
Etherios		+						√		
Exosite		√	+					√		
GroveStreams	√							√	+	
IBM IoT		√								+
InfoBright					√	+				
Jasper Control Centre	√					+		√		
KAA	+				√					
Microsoft research lab of things	√									+
Nimbits					+	√				
Oracle IoT cloud			√	√	+		√		√	
OpenRemote	√			+						
Plotly						√		√	+	
SeeControl IoT		+				√			√	
SensorCloud		+						√	√	
Temboo	+									
Thethings.io	√		+					√		
ThingSpeak	√							+	√	
ThingWorx	√				+			√		
Xively	√	+						√		

Abbreviation: + suitable, √ applicable.

remotely program the hardware, filtering the data as per the need.

Pros: Choreos based applications are supported.
Cons: Not suitable for resources intensive applications.
2) Device management

Following platforms are specialized in handling and managing devices in form of digital e.g., processing modules (Arduino, Raspberry pi etc.), and analog e.g., electrical equipments (industrial motors, rotors, and household devices).

2.4. SeeControl IoT

SeeControl (http://www.seecontrol.com) is a sole Product as a Service modeled, enterprise IoT cloud platform that is specialized at device messaging and management. Sensor data visualization, analytics, and complete work flow monitoring are done by SeeControl. Open API based push/pull architecture is deployed for massively scalable IoT products. Product modeling is the most important task which models physical things, business grouping, and events using Nexus TM Engine to transform raw data into valuable information through real time/batch processing modes. Centralized and complex firmware distribution network facility is another viable component that is motivated by data normalization supported by API data and device mapping to ERP, CRM, and EAM modules of business.

Pros: Push/Pull based devices are supported.
Cons: Visualization is not up to the mark.

2.5. SensorCloud

SensorCloud (http://www.sensorcloud.com) is a private IoT cloud that provides Platform as a Service to acquire, visualize, monitor, and analyze the data received from Lord Microstrain's wired or wireless sensors. Basically, SensorCloud is an excellent tool leverages powerful cloud computing facilities such as data scalability, rapid visualization, and user program analysis. MathEngine® analytics allow developers to perform complex mathematical operations on the data. FastGrpah and LiveConnect features help developers to process graphical functionality on the stored data uploaded by manual (CSV) or automatically (OpenData API). SensorCloud provides a RESTful API that allows any device or application to upload data it its secure cloud that is currently built on top of Amazon Web Services (AWS).

Pros: Large pool of sensor devices can be managed.
Cons: Open source devices are difficult to get served.

2.6. Etherios

Etherios (http://www.etherios.com) supports a comprehensive suite of products and services for the connected enterprises. Its Device Cloud is designed on PaaS model to enable user groups for connecting any product and gain real time visibility into their assets. The Social Machine is another cloud based tool that provides SaaS solution while integrating machine data with corresponding Salesforce.com instance for transforming it into a more powerful CRM. Etherios bridges the connectivity for modern enterprises while facilitating through thousands of off-the-shelf wired and wireless solutions designed for specific purpose. It provides custom solutions for any device with through Cloud Connector. Further, manages, monitors, and controls all connected devices from a single interface in real time. Etherios charges nil for the developers to use up to 5 devices for a span of 30 days.

Pros: Specialized clouds for devices and third party software are enabled.
Cons: Developers are restricted by selected devices.

2.7. Xively

Xively (https://xively.com) is an enterprise IoT cloud service based on Gravity Cloud technology. This LogMeIn owned platform helps companies to manage their connected product business by addressing a number of practical needs by scalable, secure, and reliable connectivity. It also paves the right business data processing services towards its IoT enabled customers, partners and vendors through flexible API connectors. Xively employs a novel IoT Platform as a Service (IoTaaS) built on its elastic public cloud. Elastic scalability of the cloud provides intuitive device lifecycle management capabilities, implying time series activities into it. Moreover, data archiving, conditional triggering, real time device provisioning cum activation, message management and routing are facilitated by Xively. To ease the control over the devices, Xively has created a developer workbench and device management console which can be operated by a novice. It is also capable top support millions of devices by RESTful APIs. Use of JSON, XML and CSV data formats have evolved its effectiveness in terms of device associatively that can be monitored through pre-assessed client libraries built on top of iOS, Android, JavaScript as well as server libraries meant for applications based on high end web languages such as, Ruby, Python, and Java.

Pros: Easy to integrate with devices.
Cons: Notification services are minimally present.
3) System management

The presented platforms herein do comply with management of system related jobs which is essential to formulate the whole infrastructure.

2.8. Ayla's IoT cloud fabric

Ayla IoT Fabric (https://www.aylanetworks.com) is an enterprise class, Platform as a Service (PaaS) modeled, simple, and cost-effective solution for OEMs for connecting any device to the Internet. Ayla Networks provides powerful software agents embedded in both connected devices and mobile device applications for end-to-end support. Ayla's Agile Mobile Application Platform (AMAP) is built upon its mobile libraries that provide an optimized mobile APP for iOS and Android users. With Ayla's framework developer can be empowered with role based access control, activity scheduling, and event notification related tasks easily. IoT data intelligence, visualization, user behavior analysis, and RESTful API enable seamless experience across user's dash board. In its operational scale, device mapping, elastic cloud computing, and device management etc. activities are enhanced to increase business agility with reduced overall risk.

Pros: Mobile application development is easy.
Cons: Not suitable for small scale developers.

2.9. thethings.io

thethings.io (https://thethings.io) platform provides a complete back end solution for IoT markers and IoT APP developers through an easy and flexible API. thethings.io is hardware agnostic and allows the connect any device that is capable to use HTTP, Websockets, MQTT, or CoAP protocols. Real time, rule based jobs can be easily monitored while developing end-to-end connectivity among the devices by leveraging device management, monotorization, and analytical supports. Real time data storage facilities are also provided to have interoperable access of the devices for fast and low cost product development. The deployment of the cloud is presently being made on top of AWS.

Pros: Device agnostic.
Cons: Lacks in self sustainace, dependant on third party web services.

2.10. Exosite

Exosite (https://exosite.com) is modular, enterprise-grade IoT software platform that helps manufacturers bring connected products to market. Underlying IoT Software as a Service (SaaS) based cloud platform provides real time data visualization and analytics support to the users. It is a hosted server based system which is enabled with web service APIs, built in infrastructural framework, lightweight and flexible back end conjugated with UDP, HTTP, and JSON RPC. Various development kits are supported for design and deployment of IoT solutions. Arduino, Microchip, TI, and Renesas prototype boards do well communicate with Exosite platform. Device client software along with shared/public data ports facilitates the attached

devices to connect and transfer the contexts through CoAP, and UDP single shot APIs. Device management, data visualization, device modeling, field provisioning, interface for reading and writing data from an IM client, creating portals dashboard widgets are the numerous tasks that are monitored by Exosite.

Pros: System development is easy.
Cons: Big data provision is lacking.
4) Heterogeneity management

This type of application domain is leveraged by following IoT cloud platforms that enable connectivity and communication issues between systems of different i.e., heterogeneous issues.

2.11. Arrayent Connect TM

Arrayent (http://www.arrayent.com) is an IoT platform enables major heterogeneous brands like Whirlpool, Maytag, and First Alert to connect users' products to value added smart hand held devices and web applications. Arrayent Connect Cloud is an IoT operating system that leverages Software as a Service (SaaS) model, helps hosting all virtualized devices through Over-the Air (OTA) firmware updates in low data latency rate. Further, its secure, reliable, and scalable data sources help users to get retrieved, processed, and delivered. Cross platform computing platforms are supported that ranges from 8-bit microcontroller to 32-bit processors. LAN agnostic behavior of Arrayent Connect makes it supportive at flelxible API abstraction layer to address both ends of product spectrum between enterprise and consumer through APPs. Email and SMS alerts are sent to the customers with iOS and Android based push notifications.

Pros: Flexible to use.
Cons: Trigger based services are lagging.

2.12. Open remote

OpenRemote (http://www.openremote.com) being an open source IoT middleware solution, allows user to integrate any device - protocol – design using available resources like iOS, Android or web browsers. Using OpenRemote's cloud service, a user can design tools for developing completely customized solutions that may leverage to integrate a variety of protocols from Wi-Fi to ZigBee. OpenRemote costs free for designers, whereas professional designers are billed in the range of €150–375 per application.

Pros: Open cloud service supported.
Cons: Too much costly for developers.
5) Data management

Following IoT platforms do excel while data management task is important for sustenance of under lying system. The below mentioned platforms are capable enough to disseminate data related operation and activities to provide in depth knowledge to users about current scenario.

2.13. Arkessa

Arkessa (http://www.arkessa.com) provides issues like overall connectivity, monitoring, control, and management between IoT based devices and enterprises. Arkessa's mission is to empower companies to tap into the IoT for development of new revenue streams through improved customer satisfaction and enhanced potential values received as data streams from remote devices. Arkessa follows PaaS model to formulate a single enterprise management portal for efficient and optimized device management services, by integrating machine data streams with the available CRM, ERP, big data and other analytics systems.

Pros: Enterprise enabled design facet.
Cons: Visualization apps are not proper enough.

2.14. Axeda

Axeda (http://www.axeda.com) is an IoT cloud based platform designed for managing connected products and machines while implementing IoT and M2M applications. According to Axeda, this platform is meant to transform machine data into valuable knowledge insights, followed by build and run of particular applications, and lastly integrate machine data with other of applications and systems to optimize business processes. Axeda's cloud platform comprises of the full spectrum of inbuilt developing and deploying application modules. It integrates M2M learning into daily business process for instance from preventative data security measures to the device provisioning and configuration etc. Out of many, it is capable of key features such as providing application service, integration framework, data management. Further, REST and SOAP APIs push Axeda to establish cloud to cloud communications by means of cellular and satellites while utilizing predefined embedded agent toolkits. Asset tracking, monitoring, passing alerts and notifications and device provisioning and configuration are its competence.

Pros: M2M based data management.
Cons: Lacks in self sustainace, dependant on third party web services.

2.15. Oracle IoT cloud

Oracle IoT (https://cloud.oracle.com/iot) is combination of four crucial parameters such as, Open-that connects any type of device from sensors to gateways; Insight-that harvests the business value of IoT data; Secure-that provides normalized end-to-end security for all types of devices, data, and heterogeneous connectivity; and Accelerate-that moves the idea very quickly to execution with minimal risk. Basically, Oracle performs acquisition, analysis, and integration of the data received from the things attached to it. While analyzing, it processes real time incoming data streams with event filtering, correlation, and aggregation. Predictive and big data analytics make Oracle increasingly responsive with anomaly detection,

and rule based alerting mechanisms. Query and visualization of large volume of data paves new insights of intelligent cloud services. Oracle IoT cloud offers several solutions, including Oracle Java SE/ME Embedded Suite, Java Card, Database, and Event Processing to meet the requirements for devices with 11 MB or more allocated storage for Java. M2M platform is ideal for testing and deployment of IoT devices.

Pros: Database support.
Cons: Lacks in open source devices connectivity due to size constraint.

2.16. Nimbits

Nimbits (http://www.nimbits.com) is hybrid cloud server that solves the Edge Computing implying IoT related services by providing a horizontal platform built on constrained embedded systems. Besides, it filters noise, runs rules and pushes important data up to the cloud servers. It is designed to allow developers to build integrated, highly scalable, and highly available clusters for data logging needs. It can run on the Google™ App Engine, Amazon EC2, Ubuntu Linux KVM based virtual machine, and Jetty (a J2EE web server) based infrastructures. Nimbits uses open data table services such as, Google™ Data Table Format for use in charting and importing into spreadsheets and third party analytics tools by implying HTTP/GET to access the history of a data point. Arduino [8] platforms are supported hereby.

Pros: Easy to adopt for developers.
Cons: Real-time query processing.

2.17. ThingWorx

ThingWorx (https://thingworx.com) is a popular data driven decision making private cloud platform. ThingWrox provides M2M and IoT based Infrastructure as a service where model based design is incorporated with SQUEAL (Search, Query, Analysis) to include search based intelligence into it. Runtime intelligence environment is the essential component of underlying working model of ThingWrox. Zero coding facility is meant for the developers to reduce the time to market situation in product delivery. At the same time, mobile interfaces are mapped using APPs which are seconded by the event driven execution engine running at the servers. Innovative 3D storage is facilitated to the millions of devices. Data normalization, protocol translation, device ingress, device egress and cloud to device connectivity are the important pillars of the efficient data governance necessitate by it. Intel developed IoT hardware platforms are readily supported.

Pros: Data intensive application building is easy.
Cons: Limited number of devices can be attached.
6) Analytics

The solutions presented herein are meant to perform statistical analytics with help of analytics analyzer tools equipped in terms of cloud.

2.18. InfoBright

InfoBright (https://www.infobright.com/index.php/internet-of-things) leverages enterprises by providing its analytical schema-Knowledge Grid architecture (IoT based analytical database platform) that empowers businesses to store, analyze, and act upon pile of machine generated data while paving the communication paths among leading business intelligence platforms (e.g., Cognos, Pentaho, Talend, Jaspersoft, Microstrategy etc.) to embark on fully interconnected business ecosystems. It comes with a variety of market versions (e.g., community and enterprise) for the companies that require InfoBright compatible performance and capability issues. Besides, it is well equipped with distributed query and load performance engines capable for loading TBs per hour and can handle Peta Bytes of data while facilitating data compression in the range of 10:1–40:1. Though, community edition is given free to the developers, enterprise edition may also be availed free for a stretch of 30 days trial period.

Pros: Knowledge Grid architecture and big data processing.
Cons: Statistical services are lacking.

2.19. Jasper Control Center

Jasper Control Center (https://www.jasper.com) is the highly configurable Jasper Control Board Platform that is customizable to suit users' specific operational needs, business models, and requirements across all industries and around the world. Specifically, Control Center automates and controls the connected devices to analyze behavioral patterns and performance through real time monitoring. Rule based configuration of automated activation processes help in defining the service alerts and campaign events to incorporate the maintenance of full network for segmentation and scoring purposes. Application domains such as, manufacturing, security, home automation, commercial transportation, and retails are the main target areas of Control Center. Real time diagnosis of actionable insights to optimize device performance, ensure service reliability. MQTT, CoAP, and customized APIs support in data push/pull to and from application layer of Jasper.

Pros: Rule based behavior patterns enabled.
Cons: Suitable for automation services.
7) Deployment management

It includes planning, designing, building, testing and deploying new software and hardware components in the live environment. It is important to maintain integrity of live environment by deploying correct releases [14].

2.20. Echelon

Echelon (http://www.iiot.echelon.com) is a novel Industrial Internet of Things (IIoT) [6] based cloud platform with a full suite resources, comprising micro chips, protocol stacks,

hardware modules, communication interfaces, and management software packages for development of devices in peer-to-peer communities and applications. Echelon is distinguishable from a consumer centric IoT cloud platform by addressing the fundamental requirements for the IIoT, including autonomous control over devices, industrial strengthening reliability, support for legacy based evolution, and security mandates. Parameters like REST APIs, IzoT Python Package included IzoT based Device Stack, publish/subscribe based massage transmission altogether build up myriad load control over the distributed devices in Echelon ecosystem.

Pros: Industrial perspective.
Cons: Lacks in development scenario for beginners.
8) Monitoring management

Following IoT clouds do play important role to prevent network disaster and keep the network healthy. Ability to provide overall seamless integration with system do result in an unobtrusive form of on-line monitoring through out the time.

2.21. AerCloud

AerCloud (http://www.aeris.com) is a cloud platform for collecting, managing, and analyzing sensor data for IoT and M2M applications. AerCloud a development of Aeris, enables user applications through a seamless scalability towards millions of devices while ensuring reliability, security, and time-series database associatively. AerCloud is delivered as a Platform as a Service (PaaS) which offers pay-as-you-grow model by implying a rules engine that processes data in real time manner. CoAP and MQTT protocols supported AerCloud is empowered with REST API that provides push/pull the data to applications/applications to data, on demand.

Pros: Scalable M2M services.
Cons: Not suitable for developers.

2.22. ThingSpeak

ThingSpeak [2] (https://thingspeak.com) is an open IoT data platform based on public cloud technology. ThingSpeak enables real time data collection, analysis and actuation with an Open API. With apps and plugins, data storage, visualization, monitoring and integration of user's data with a variety of third party platforms, including leading IoT platforms such as ioBridge, Arduino, Twilio, Twitter, ThingHTTP, MATLAB have been made possible. Sensor data is collected into each channel that has eight fields which can hold any type of data, three location fields, and one status field. Various apps such as, TimeControl (automatically perform actions at predetermined times with ThingSpeak app), TweetControl (listen to the Twitterverse and react in real time), React (reacts when channel data meets some certain condition), TalkBack (queue up command for user's device) improve the reaction measures.

Pros: Public cloud enablement with triggering facility.
Cons: Less number of device connectivity simultaneously.
9) Visualization

The following IoT clouds are exceptionally good at facilitating full fledged and quantifiable graphical visualization tools to apprehend the systems' activities on screen through graphical format.

2.23. Plotly

Plotly (https://plot.ly) is a popular public data visualization cloud service provider. Plotly provides community, professional and enterprise data storage, visualization and analytics services to the ordinary or IoT applications. Excel, CSV and XML data formats are used to upload the data to its cloud servers. Python, R, MATLAB and Julia based APIs are implemented in Plotly. Graphics libraries such as, ggplot2, matplotlib, MATLAB chart conversion techniques empower the visualization. Among many, HDF5, SAS, SPSS, MS Access and ZIP file formats are used to temporarily store the data before uploading to cloud. Pdf, svg and eps vector exports facilities are incorporated into it. LDAP and directory integration are another pillar of huge popularity behind Plotly. Node.JS supported 3D chart framing enable user data to get suitably processed from Arduino, Raspberry Pi and Electric Imp hardware devices.

Pros: Best visualization tools supported for IoT.
Cons: Limited amount of storage facility.

2.24. GroveStreams

GroveStreams (https://thingworx.com) is a popular public data visualization cloud. Its patent pending data streaming analytics technology captures, analyzes, and act on massive amounts of time series data and data points as soon as it arrives at the cloud servers. Its sample time varies between 1 s and 1 year. Various data types including short, int, long, text, geo-coordinates, time etc. are supported. Customizable drag and drop facility is enhanced when live charts and grids are embedded with user needed forms that is too automatic registration process. Event Monitoring, location tracking ad mobile application are easily maintained with customizable email, SMS and HTTP call notifications. Arduino, SmartThings, Electric Imp and Raspberry Pi are supported devices. Device data analytics is performed with help of RESTful API.

Pros: Seamless event monitoring enabled.
Cons: Statistical services are lacking.
10) Research

The IoT clouds presented herein do help researchers to evaluate their cloud centric designs by simulating hence reducing the overhead of actual implementation. This minimizes the risk of monetary loss and time duration to market.

2.25. Microsoft research Lab of Things

Lab of Things [4] (http://www.lab-of-things.com) is an open IoT platform developed by Microsoft for experimental research purposes mainly for academic institutions. Typically, it is meant to be used for interconnecting between devices, implementation of various application scenarios, deployment of case studies, monitoring of field implications, and sharing of data using HomeOS4. Applications may fall within domains like health care, energy management, home automation and many more. Lab of Things consists of a client side component-HomeOS [11], and cloud services deployed in Windows Azure. Experimental APPs such as, alert notification, motion detection through camera, sample data collection from sensors, and Z-Wave [12]supported actuator control, are place on top of application layer. Public cloud assisted system is deployed on Windows based PC (HomeHub).

Pros: Suitable for home automation.
Cons: Lacks in IoT supported APIs.

2.26. IBM IoT

IBM IoT cloud (https://internetofthings.ibmcloud.com) platform is an organized architecture made to provide securely and ease at device connectivity, from standalone chips to intelligent appliances to applications and complex industry solutions. IDentity as a Service [5] (IDaaS) is the backbone of its cloud, can be expressed as an authentication infrastructure-built, hosted, and managed by third-party service provider that may be thought of as Single Sign-On (SSO) for the cloud itself. Devices such as, ARM mbed, Arduino, Intel Galileo etc. can be attached to IBM cloud using the open, lightweight MQTT messaging protocol. IBM IoT foundation is the hub of all the things where developer can setup, build, and manage the connected devices so that APPs can access their real time data. RESTful and real time APIs help in connecting the data coming frim the devices to the IBM Bluemix where applications can be created by the developer. NoSQL, Dash, and Time Series data bases are associated with IBM cloud. Hadoop governed IBM analytics and geospatial analytics are performed at this end. Device management related operations such as, manage, update, diagnostics, observations, and monitoring of device and firmware actions can be sought out of it.

Pros: Device identity is enabled.
Cons: Difficult for application prototyping.

3. Problems of the existing IoT cloud platforms

The existing cloud solutions have incorporated IoT based smarter applications for solving a number of challenges in various fields. I discuss the few important prospects of these applications to improve the existing solutions as below, whereas the following sections shall show the path to improve the current situation point-wise.

A. *Standardization:* Current clouds do not conform to the standardized format of representation of data as well as the process. Standardization is a core component which may precisely be operated for growth of IoT centric applications. Standardization in IoT cloud signifies to lower down the initial barriers for the service providers and active users, improvising the interoperability issues between different applications or systems and to perceive better competition among the developed products or services in the application level. Security standards, communication standards and identification standards need to be evolved with the spread of IoT cloud technologies while designing emerging technologies at a horizontal equivalence. In addition, fellow researchers shall document industry-specific guidelines and specify required standards for efficient implementation of IoT.
B. *Heterogeneity:* IoT is a very complicated heterogeneous network platform. But the mentioned few clouds are unable to interact with heterogeneous modules or communication technologies. This, in turn enhances the complexity among various types devices through various communication technologies showing the rude behavior of network to be fraudulent, and delayed. Bandyopadhyay et al. [13] have clearly mentioned that the management of connected objects by facilitating through collaborative work among different things (hardware components or software services) and the administering them after providing addressing, identification, and optimization at the architectural and protocol levels is a serious research issue. However, to succeed at the specified domain, IoT clouds need to be reassessed to sort out the depletion of the common platform.
C. *Context awareness:* When billions of sensor enabled things are connected to the Internet, it may not be feasible for the user group to handle all the data collected by the sensors. Context-awareness computing techniques need to be used in better way to help decide what data needs to be processed. Discussed clouds have limited capability in terms of context awareness. This seems to ascertain the negation of information validation in form of continuous disrupted process. Surrounding environmental parameters and self assessment may transfer the localized context to others while making a well connected self cum periphery aware IoT cloud ecosystem.
D. *Middleware:* Most of the presented clouds follow the vertical silos designed for specified sole domains. A middleware could provide a common platform to achieve the specific goals incorporating multi-localized (geographically) modules within a tenant. Middleware paves the horizontal flow of information among the devices, protocols, and applications with respect to itself. Applications can be performed over the whole data set and query be processed on the connected devices in a centralized manner. IoT clouds necessitate the incorporation of more number of middleware to run with.
E. *IoT node identity:* The IoT is envisaged to include an incredibly high number of nodes. All the attached devices

and data shall be retrievable; here in such context, the unique identity is a must for efficient point-to-point network configuration. IPv4 protocol identifies each node through a 4-byte address. As it is well known that the availability of IPv4 numbered addresses are decreasing rapidly by reaching zero in next a few years, new addressing policies shall be countered where IPv6 is a strong contender. Presented systems do mostly use IPv4 for communication. But futuristic network may highly be populated so that the unique identity would get difficult to be imposed upon the nodes. Improved techniques to be alloyed with the current approach. Few of the existing IoT clouds comply with IPv6 that should be increased in coming years.

F. *Energy management:* Energy management is the most important issue in IoT cloud based systems. System components such as IoT devices, network antennas, and other dependent passive modules along with the core algorithms should properly be readdressed while indulging into the harvesting of energy. Otherwise, non-conventional source of energy harvesting solutions such as solar power, wind, biomass, and vibration cloud also be tested while designing IoT based cloud systems. Hence, researchers may get involved to work on the other sources in future.

G. *Fault tolerance:* Fault tolerance is mostly absent in the above solutions. To make a flawless system, fault tolerance level of the system should be kept very high so that despite of technical error, the system keep working. Hardware modules may fail due to depleted battery or any other reason. Similarly generation of erroneous value by the sensor, faulty calibration, and failure in communication may develop a fault situation. While seeking for solution, solar power may give an alternative to the battery operated modules. Usage of multitude of communication protocol may increase the power consumption but always provide seamless connectivity. Power consumption in such case, may be lower down by enacting one protocol to get activated at any instance. Proper calibration need to be done prior to final installation. IoT clouds need to get revamped with improved utilization of energy aware algorithms, and deployment procedures to lower down the power consumption.

4. Discussions and conclusions

Application domain specific survey of IoT cloud platforms have been performed in this paper by including 26 different IoT clouds which vary according to 10 specific genres of applications. It is found that heterogeneity management, analytics, visualization, and research centric clouds do lack in overall percentage at current scenario. Trend of cloud growth seems to be in favor of device management, data management, and application management oriented designs. It is also seen

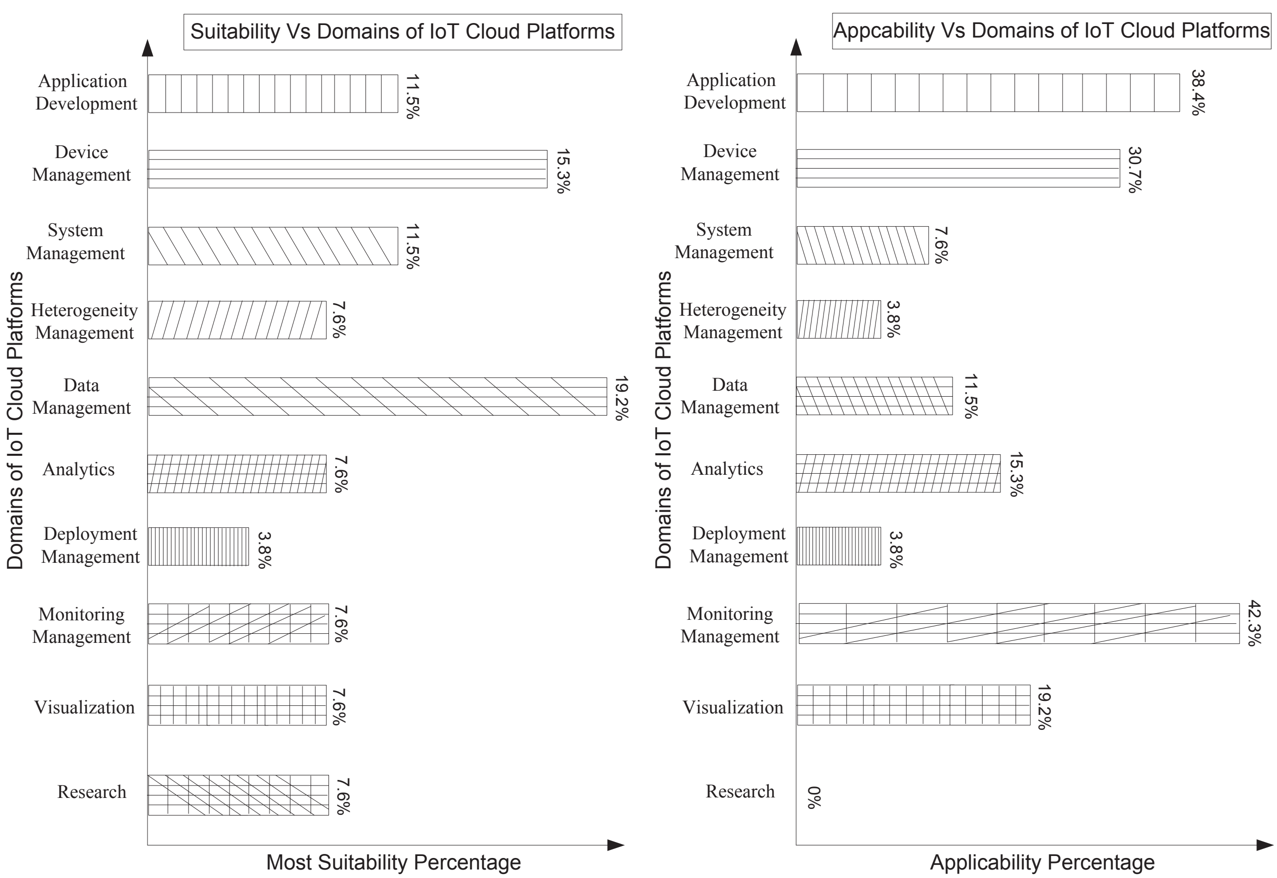

Fig. 2. Histogram of most suitability and applicability domain specific charts derived from Table 1.

that a particular IoT cloud is capable of serving multitude of domains. Research specific clouds are very less in number which should be developed more for the proper comprehension of performing real life IoT based experiments by the scientific communities. Application development and monitoring management seems to be the mostly served domains by the current IoT clouds. However, the IoT clouds do verge along with the presented genres of specificity they need rigorous checking in terms of context awareness, big data handling, and sensor management issues in detail. Although, 26 different IoT cloud platforms are intensively studied, none of these are perfect in every terms and aspects of developers. Some lacks in visualization capability whereas some in open source IoT APIs. It is up to the users or developers who wish to pick appropriate IoT cloud as per his/her requirement. Short description of pros and cons of each IoT cloud shall enable users to select the needed service.

Fig. 2 (see left) shows the results obtained from Table 1 where suitable and applicability issues are depicted. Out of 26 IoT cloud platforms, Data management based platforms are currently trending in the market scoring 19.2%. Device and application management domains are performing same in IoT market valuing 11.5%. Heterogeneity, analytics, monitoring, visualization and research domain are equally valuating 7.6%. Deployment management is at the lowest priority at present time i.e., 3.8%. While looking at applicability graph (Fig. 2 see Right) values are changed. The reason behind is same IoT platform is chosen applicable for different domains. Monitoring management is leading at the moment with 42.3% of score. Application development, device management and visualization domains are standing at 2nd, 3rd, and 4th positions while scoring 38.4%, 30.7% and 19.2%, respectively. Applicability of research domain is 0%, because no other IoT cloud platforms are applicable in this domain.

Looking at the applicability chart, it is comprehended that IoT cloud platforms are more or less actually doing well. However, it is also suggested that research centric IoT cloud platforms need to be developed for real life experimentation by the enthusiasts, scientists, and educators.

As learnt from this research, survey of IoT valued big data clouds shall be performed in near future. Similarly, IoT cloud platforms while incorporating time series data base may be reviewed in future work. The overall approach of this paper is to listing of emerging IoT clouds into the market according to their applicability and usability in various forms. Readers of all genre may take this article as a standard before going into the details of selecting of various cloud solutions.

References

[1] https://www.profitbricks.com. [Accessed 2 February 2016].

[2] https://thingspeak.com/docs/tutorials#analyze. [Accessed 11 January 2016].

[3] https://temboo.com/library/Library/Labs. [Accessed 8 February, 2016].

[4] http://research.microsoft.com/en-us/projects/homeos/. [Accessed 20 February 2016].

[5] http://searchmobilecomputing.techtarget.com/definition/identity-as-a-Service-IDaaS. [Accessed 22 March 2016].

[6] Xu L, He W, Li S. Internet of things in industries: a survey. IEEE Trans Ind Inf 2014;10(4):2233−43.

[7] LoRa. https://www.lora-alliance.org/. [Accessed 21 February 2015].

[8] Arduino. http://arduino.cc. [Accessed 20 March 2015].

[9] NoSQL. http://nosql-database.org. [Accessed 12 February 2015].

[10] Apache Hadoop. https://hadoop.apache.org/. [Accessed 25 February 2016].

[11] HomeOS. http://research.microsoft.com/en-us/projects/homeos/. [Accessed 2 February 2016].

[12] Z-Wave. www.z-wave.com. [Accessed 21 February 2016].

[13] Bandyopadhyay D, Sen J. Internet of things: applications and challenges in technology and standardization. Wirel Personal Commun 2011;58(1): 49−69.

[14] Release and deployment management. www.tutorialspoint.com/itil/release_and_deployment_management.htm.

[15] Ray PP. Internet of things based physical activity monitoring (PAMIoT): an architectural framework to monitor human physical activity. In: Proceeding of IEEE CALCON, Kolkata; 2014. p. 32−4.

[16] Ray PP. Home health hub internet of things (H3IoT): an architectural framework for monitoring health of elderly people. In: Proceeding of IEEE ICSEMR, Chennai; 2014.

[17] Ray PP. Internet of Things for Sports (IoTSport): an architectural framework for sports and recreational activity. In: Proceeding of IEEE EESCO, Vizag; 2015. p. 79−83.

[18] Sebastian S, Ray PP. Development of IoT invasive architecture for complying with health of home. In: Proceeding of international conference on computing and communication systems (I3CS), Shillong, 2015. pp. 79−83.

[19] Sebastian S, Ray PP. When soccer gets connected to internet. In: Proceeding of international conference on computing and communication systems (I3CS), Shillong, 2015, pp. 84−88.

[20] Ray PP. Internet of things cloud enabled MISSENARD index measurement for indoor occupants, measurement, vol. 92. Elsevier; 2016. p. 157−65.

[21] Ray PP. A survey on internet of things architectures, EAI endorsed transactions on internet of things. J King Saud Univ Comput Inf Sci 2016. http://dx.doi.org/10.1016/j.jksuci.2016.10.003.

[22] Ray PP. Creating values out of internet of things: an industrial perspective. J Comput Netw Commun 2016. http://dx.doi.org/10.1155/2016/1579460.

[23] Ray PP. Internet of things cloud based smart monitoring of Air borne PM2.5 density level. In: IEEE international conference on Signal Processing, Communication & Embedded Systems (SCOPES), Paralakhemundi, Odisa, India; 2016 (Accepted).

[24] Babu SM, Lakshmi AJ, Rao BT. A study on cloud based internet of things: CloudIoT. In: Proceedings of 2015 global conference on communication technologies, 2015, pp. 60−65.

[25] Emeakaroha VC, Cafferkey N, Healy P, Morrison JP. A cloud-based IoT data gathering and processing platform. In: Proceedings of 3rd international conference on future internet of things and cloud, 2015, pp.50−57.

[26] Kantarci B, Mouftah HT. Sensing services in cloud-centric internet of things: a survey, taxonomy and challenges. In: Proceedings of IEEE ICC; 2015. p. 1865−70.

[27] Alessio Botta, Walter de Donato, Valerio Persico, Antonio Pescapè. On the integration of cloud computing and internet of things. In: Proceedings of international conference on future internet of things and cloud, pp. 23−30, 2014.

[28] Suciu G, Vulpe A, Fratu O, Suciu V. M2M remote telemetry and cloud IoT big data processing in viticulture. In: Proceedinsg of IEEE IWCMC; 2015. pp. 1171−1121.

[29] Wang L, Ranjan R. Processing distributed internet of things data in clouds. IEEE Cloud Computing; 2015. p. 76−80.

[30] Nastic S, Sehic S, Le DH, Truong H, Dustdar S. Provisioning Software-defined IoT Cloud Systems. In: Proceedings of international conference on future internet of things and cloud, 2014, pp. 288−295.

[31] Nastic S, Copil G, Truong H, Dustdar S. Governing elastic IoT cloud systems under uncertainty. In: Proceedings of IEEE 7th international conference on cloud computing technology and science, 2015, pp. 131−138.

[32] Truong H, Dustdar S. Principles for engineering IoT cloud systems. IEEE Cloud Computing; 2015. p. 68−76.

[33] Kum SW, Moon J, Lim T, Park J. A novel design of IoT cloud delegate framework to harmonize cloud-scale IoT services. In: Proceedings of IEEE ICCE; 2015. p. 247−8.

[34] Celesti A, Fazio M, Giacobbe M, Puliafito A, Villari M. Characterizing cloud federation in IoT. In: 30th international conference on advanced information networking and applications workshops, 2016, pp. 93−98.

[35] Taherkordi A, Eliassen F. Scalable modeling of cloud-based IoT services for smart cities. In: Proceedings of first IEEE international workshop on context-aware smart cities and intelligent transport systems; 2016.

[36] Fortino G, Guerrieri A, Russo W, Savaglio C. Integration of agent-based and cloud computing for the smart objects-oriented IoT. In: Proceedings of IEEE 18th international conference on computer supported cooperative work in design, 2014, pp. 493−498.

[37] ITU-IoT definition. http://www.itu.int/ITU-T/newslog/New+ITU+Standards+Define+The+Internet+Of+Things+And+Provide+The+Blueprints+For+Its+Development.aspx. [Accessed 4 July 2012].

[38] What is a cloud platform? www.adrianotto.com/2011/02/cloud-platform/. [Accessed August 13 2016].