UNIVERSITY OF RWANDA

Research and Postgraduate Studies (RPGS) Unit

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Thesis Title: "**The *Design of a service level architecture for handling big data using mobile cloud computing and Internet of things***"

Student's Name: MUYANGO Charles

College of Science and Technology

School of Information and Communication Technology (SoICT)

Master of Science in information systems

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Thesis Title: "**The** ***Design of a service level architecture for handling big data using mobile cloud computing and Internet of things***"

By

Name: MUYANGO Charles

Registration Number: 215036934

A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER OFSCIENCE IN INFORMATION SYSTEMS

In the College of Science and Technology

Supervisor: Prof. Santhi Kumaran

June 2016

Declaration

I declare that this Dissertation contains my own work except where specifically acknowledged

Student Name and Number

MUYANGO Charles

Reg no: 215036934

Signed………………………………………..

Date…………………………………………..

Research and Postgraduate Studies (RPGS) Unit

Certificate

This is to certify that the project work entitled **"The *Design of a service level architecture for handling big data using mobile cloud computing and Internet of things*.**" *is a record of original work done by MUYANGO Charles. with Reg no: 215036934 in partial fulfillment of the requirement for the award masters of science in information systems of College of Science and Technology, University of Rwanda during the academic year 2015-2016*

Prof. Santhi Kumaran	Mr. MATOVU Moses
………………………..	………………………
Supervisor	Head Dept of IS

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Abstract

The tremendous continued increase of connecting different devices (things) fitted with sensors and actuators to different networks using different technologies produce huge amounts of data that will require the availability of increased storage and processing power that will be provided by mobile cloud computing systems. The development of the internet of things paradigm has led to a research on machine to machine communication and this has allowed more sources of data to be collected and held for longer times in order to be processed by powerful cloud based applications and big data techniques.

Therefore there is no existing way how the huge amount of data produced by the internet of things are going to be handled and used by mobile devices that will communicate both in real time and non real time leading to heterogeneity and non- interoperability issues.

The above problem may be solved through designing reference architecture for handling big data using Mobile Cloud Computing and Internet of Things that will lead to their integration hence allowing the heterogeneity and interoperability of various devices.

The benefit of this project is that the designed service level architecture will represent the integration of big data, Mobile Cloud Computing and Interne of Things. It will also indicate how they (BD, MCC & IOT) will communicate hence achieving the targeted audience's goals of attaining integration, heterogeneity, scalability, and interoperability to all different services involved.

In conclusion, the designed architecture will handle big data using mobile cloud computing and Internet of things consequently achieving the integration of the three new innovative technologies ie Big Data, Mobile Cloud Computing & Internet of Things resulting in both the scalability and interoperability of different devices produced by different vendors.

Key words: Internet of things, Big data, Mobile Cloud computing and interoperability.

List of acronyms

AAA	Authentication and Accounting
BD	Big Data
CaaS	Collaboration as a Service
CRM	Customer relationship Management
HA	Home Agent
HR	Human resource
IaaS	Infrastructure as a Service
IBM	International Business Machine
IOT	Internet of Things
MCC	Mobile Cloud Computing.
NFC	Near Field Communication.
NIST	National Institute of Standards and Technology
ORA	Oracle Reference Architecture
ODCA	Open Data Centre Alliance
PaaS	Platform as a Service
RFID	Radio Frequency Identifier
SaaS	Software as a Service
SLA	Service level Agreement
StaaS	Storage as a service
WSN	Wireless sensor Networks

List of Figures

Table of Contents

Chapter 1 General Introduction

1.0. Introduction

Big Data can be characterized by the 3 ‘Vs of Volume (size of the data), Variety (range in type and source of data) and Velocity (frequency of data generation) [1]. It includes capture, storage, search, sharing, transfer, analysis and visualization. Big data is generated by interconnecting different many devices as shown in Figure 1-1 through internet of things which is an emerging technology.[2]

Mobile cloud computing (MCC) according to [3], refers to an infrastructure where both the data storage and data processing happen outside of the mobile device. Mobile cloud applications move the computing power and data storage away from the mobile devices and into powerful and centralized computing platforms located in clouds, which are then accessed over the wireless connection based on a thin native client.

Aepona [4] describes MCC as a new paradigm for mobile applications whereby the data processing and storage are moved from the mobile device to powerful and centralized computing platforms located in clouds. These centralized applications are then accessed over the wireless connection based on a thin native client or web browser on the mobile devices.

Internet of things is where objects whether living things or non living things are embedded in with sensors or actuators so that they may be connected in a network and this allows them to receive, process, store and send data. There could potentially be billions of such devices connected across the Internet with predictions of 50 to 100 billion devices being connected to the Internet by 2020 [5]&[6].The increase in device connectivity will be due to IOT and this will produce an exponential increase in data and this is where Big data intersects with IOT [7]

Since they may have small storage capacities, a mobile cloud computing cloud technology is employed and in place to help these objects to store their data and consequently enable them to be scaled, monitored and secured.

Therefore, for these devices to easily communicate, a hierarchy of functions, protocols, services, guidelines and standards have to be followed that will result in a need to develop a service level architecture.

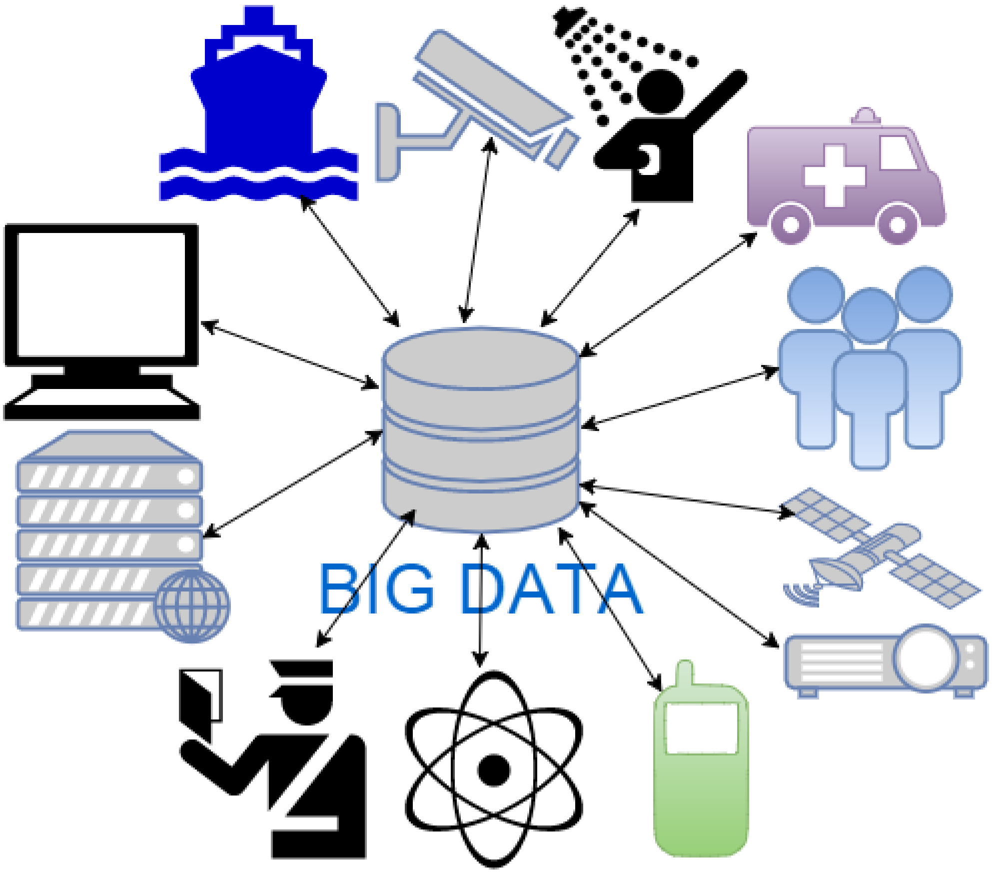

Figure 1-1: Shows interconnection of different things

1.1. Motivation

As more and more living and non-livings things are being interconnected on different networks in the internet with different innovative technologies, more storage and processing facilities are required to hold data for a long time, hence big data systems are needed to interact with mobile cloud computing and internet of things thus my interest was caught on that fact that businesses and technologies will effect their communications, collaborations and consequently an architecture is required to ease their interoperability, scalability ,availability, security and heterogeneity.

1.2. Statement of the problem

The various internetworked devices (things) produce huge amount of data and with the current outburst usage of the smart mobile phones and tablets, Things communicate and function with difficulty hence there is less efficiency, less availability of resources, poor security and less scalability.

In order to effectively increase efficiency, availability, security and scalability, a service level architecture has to be designed so as to create the interoperability and heterogeneity of the connected devices made by different developers and manufacturers' through the system integration.

1.3. Objectives of the project

1.3.1 General objective

To design a service level architecture for handling big data using mobile computing.

1.3.2 Specific objectives

- To develop an architecture that will lead to integration of different services involved in the big data system.
- To create an architectural environment where all the networked devices will interoperate.

1.4. The scope and Limitations of the project

The research will be limited to the interaction and collaboration between the Big data, Mobile cloud computing and Internet of things.

1.5. Challenges

- Lack of expertise in cloud computing, IOT, Mobility and Big data.
- Dynamic connectivity capability.
- Difficulty in integration with existing enterprise architectures to realize business benefits.
- Real time multimedia content processing and massive scaling issues.

1.6. Organization of the Study

The project is organized into five chapters as follows with brief overview of each:

Chapter one includes an introduction, problem statement, general and specific objectives and all necessary information for the understanding of the concepts that discussed in the later chapters.

Chapter Two discusses the literature review with description of the different aspects relating to the research area. The existing architectures deal with big data processes, security and management.

Chapter Three focuses on methodology steps that are used in the research. The design will be practice driven and not from the scratch.

Chapter Four illustrates our design of the proposed architecture. The integration of the BD,MCC & IoT allows the heterogeneity and he interoperability of different services that are easily secured and managed.

Chapter Five includes the conclusion and recommendations. At the end of the paper, the references used in the research as well as the appendices have been included.

1.7. Conclusion

In this Chapter, the problem statement and motivation have been stated, the project's objectives, challenges and its limitations indicated. The issue of the architecture design will be addressed in chapter 4.

Chapter 2 Literature review

2.0. Introduction

Big Data, Mobile Cloud Computing and Internet of Things are new innovative technologies that co-exist. A number of standards, blog posts and some of literatures such as books, journals, reports and others, have been used and referenced to get to an understanding of what is? How they operate? How they are applicable. Therefore some of the existing reference architecture are to be reviewed and used to analyse the way how the ideas got will be used to design an architecture for handling big data using MCC and IoT. The referenced architectures are shown in appendices.

2.1. NIST Cloud computing reference architecture

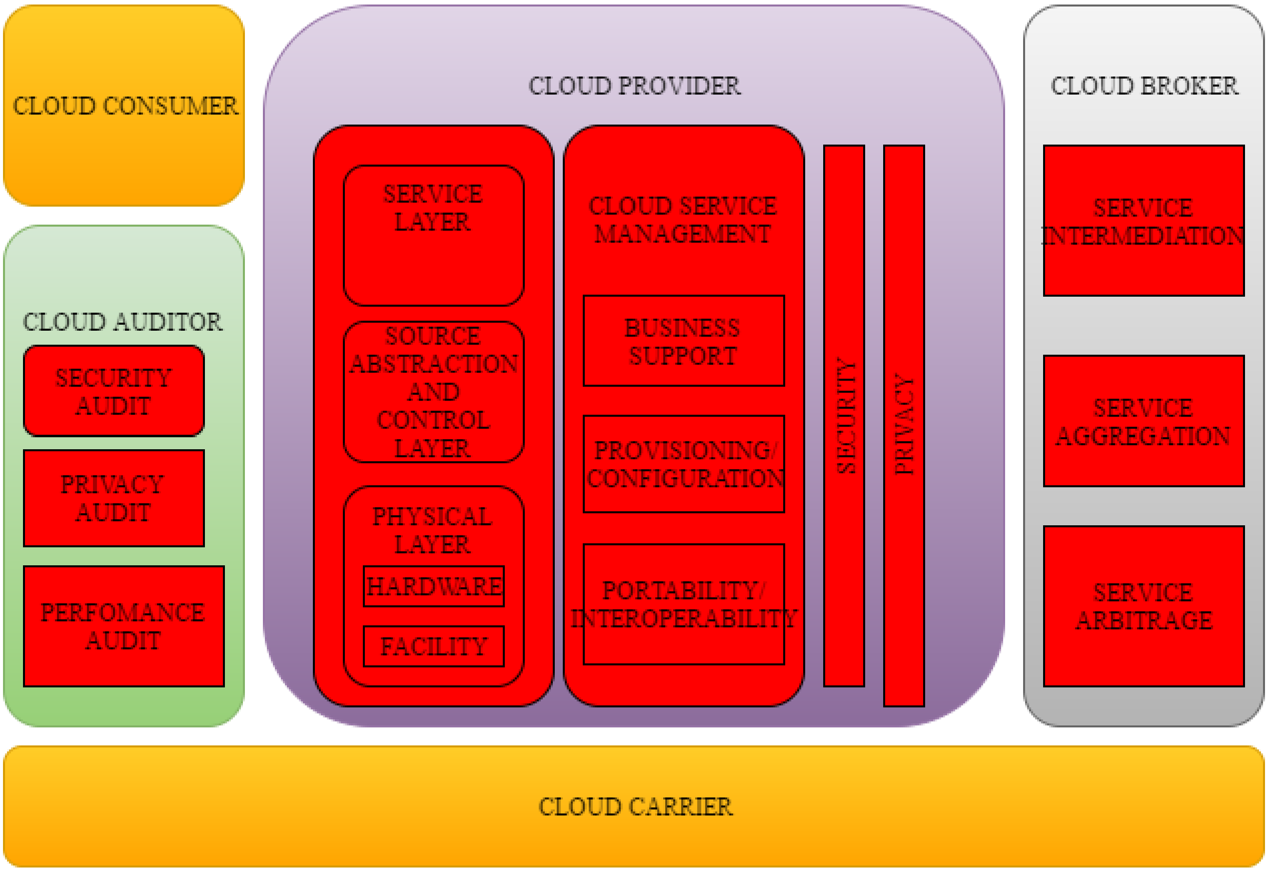

Figure 2-1: NIST cloud computing Reference Architecture [8]

NIST focuses on the requirements of what cloud service provides and not on its implementation.

However the architecture hinges on the Portability, interoperability and security requirements together with guidance and standard. This is shown in figure 2-1.[8]

It describes five actors: cloud consumer, cloud carrier, cloud broker, cloud auditor and cloud provider, and three service models: IaaS, PaaS and IaaS [9]&[10].

2.2. The IBM Business Analytics and Optimization Reference Architecture

It is an architecture that supports high volume unstructured and structured streaming data sources such as video, TV, audio, voice, emails, chats, radio news, transactional data.

Its purpose is to inform and guide IBM sales, services and professionals who are involved in designing and deploying IBM Big Data and Analytics solutions with the clients. It describes each of the IBM software products that support a Big Data &analytics solution by capability as shown in figure 2-2[11].

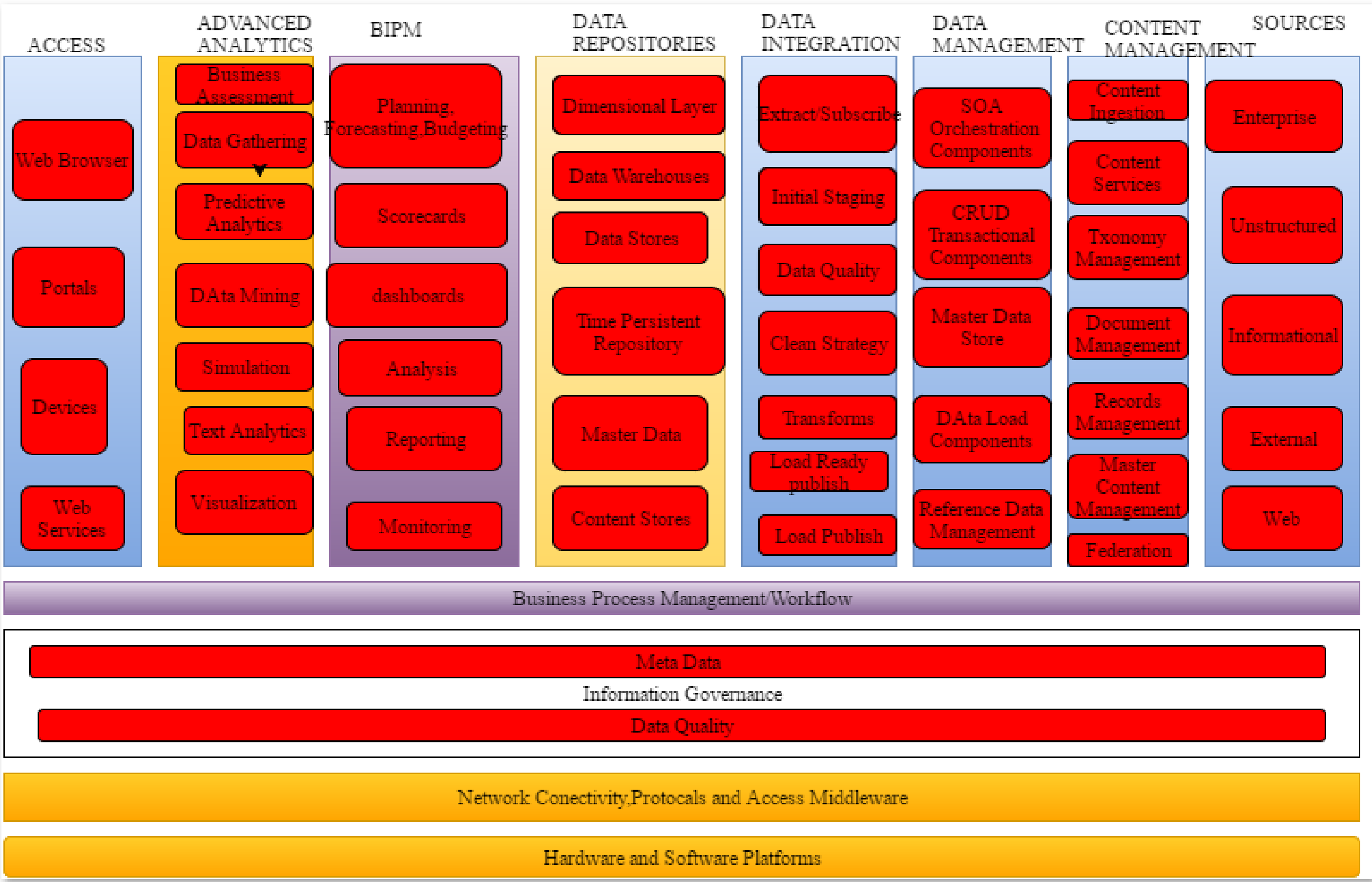

Figure 2-2: The IBM Business Analytics and Optimization Reference Architecture [12]

It also provides execution platform and services for user developed applications that filter, analyse data. It batches in data from a data warehouse, cloud, databases and streams programs to be updated or changed as it is running without restarting.

Finally it supports data integration by providing read and write of heterogeneous data sources. It enables you access data anywhere in your enterprise no matter where it resides regardless of its format or vendors [13].

2.3. Oracle Big Data Reference Architecture.

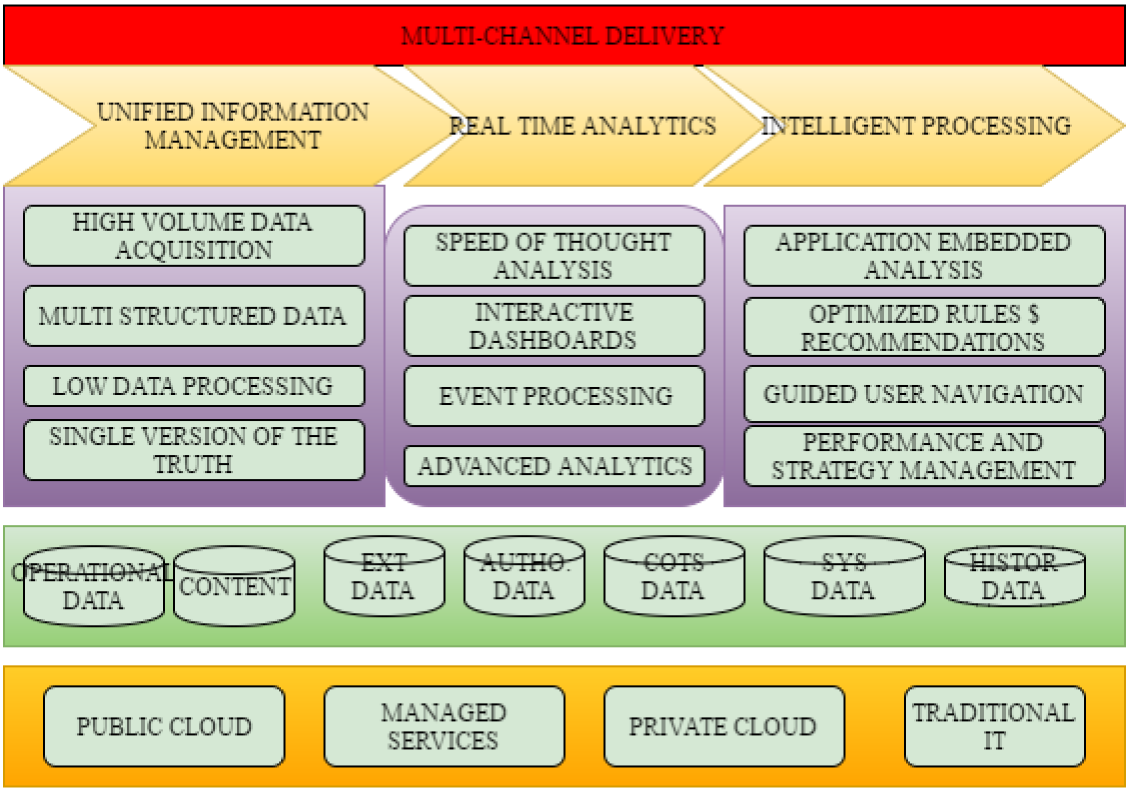

Figure 2-3: Big data & analytics reference architecture [14]

The architecture shown in the Figure 2-3 above uses capabilities to provide a high description of the big data and data analysis solution so as to accomplish its major objective of attaining high performance and scalability.

In reference [14], the ORA defines a multi-tier architecture framework that describes many types of technology solutions and focuses on Real-time analytics e.g event processing and advanced analytics, Unified Information Management that manages information historically e.g high volume data acquisition, multi-structured data organization and discovery, and Intelligent Process aspects like performance and strategy management , optimizes rules and recommendations

2.4. Big data ecosystem architecture

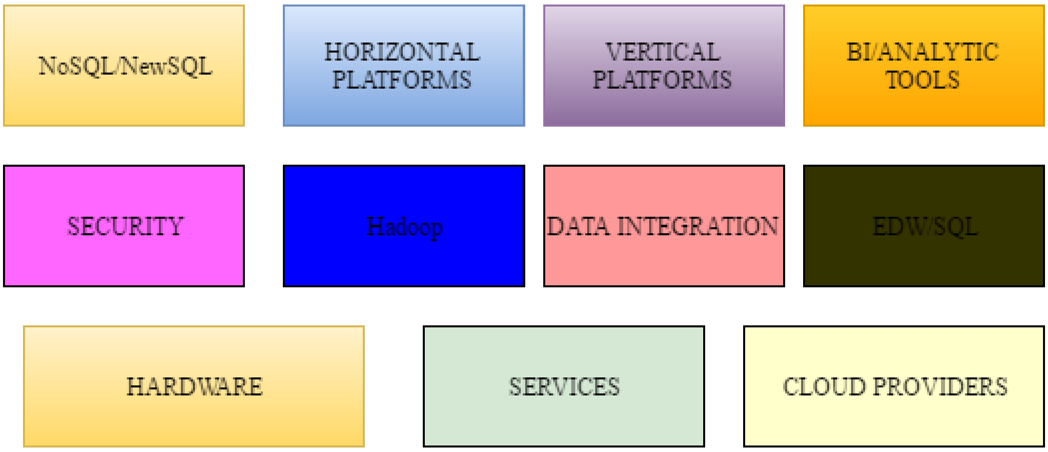

Figure 2-4: Big Data Ecosystem Architecture [15].

Figure 2-4 shows the broad view of the variety of data stores for different data structures, different methods of search and query, different algorithms and approaches to analyze, store, recombine both structure and unstructured data. It discusses the main capabilities required for a more scoped view of Big Data, it also indicates the broad set of capabilities of the Big Data Ecosystem, technologies-[15]&[16].

2.5. The reference architecture

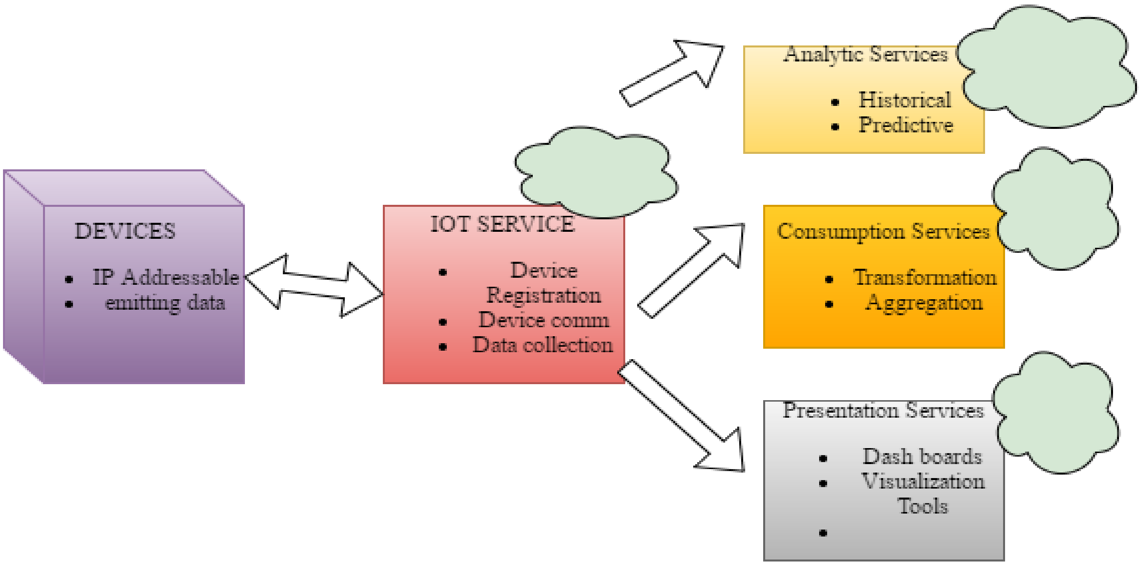

Figure 2-5: IOT Reference Architecture [16].

Internet of Things at a very high level is not complicated. It all comes down to data, lots of data. By 2020 there will be hundreds of billions of devices connected to the internet and feeding exabytes of data to the cloud on a daily basis. It is the software that we create that will take that data and turn it into business insight-[16].

Figure 2-5 therefore focuses on options for dealing with the massive amount of data that comes streaming in from connected devices-[17].

2.6. TMF Big Data Analytics Reference Architecture

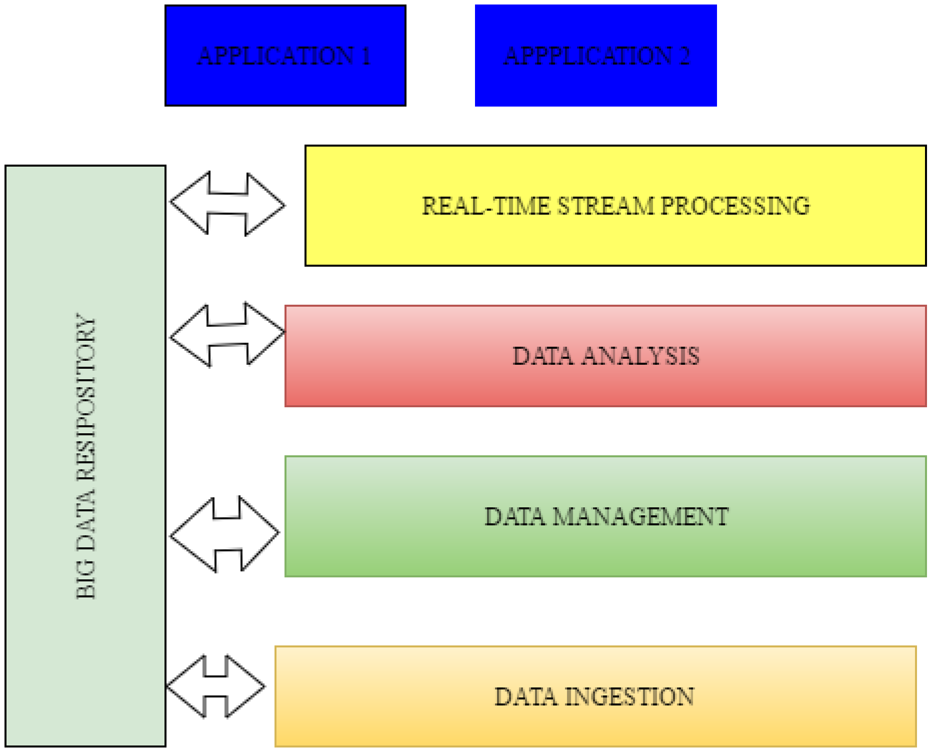

Figure 2-6: TMF big data analytics reference architecture [18].

Figure 2-6 illustrates an architecture which provides lower cost effective for data storage with better processing mechanism which has led to add value to existing data.

It is a standard architecture for handling data ingestion, data management, data analysis and real time stream processing being accessed in the big data repository [18].

It is a streaming analytics platform that combines real-time streaming, discovery, analysis, visualization and action, which drastically improves high performance of the system and supports scalability of devices connected to it from different developers [19].

2.7. Big Data Reference Architecture

Most Big Data projects use variations of Big Data reference architecture. Understanding the high level view of this reference architecture provides a good background for understanding Big Data and how it complements existing analytics, big data intelligence, databases and systems [20].This architecture is not a fixed, one-size-fits-all approach. Each component of the architecture has at least several alternatives with its own advantages and disadvantages for a particular workload. Companies often start with a subset of the patterns in this architecture, and as they realize value for gaining insight to key business outcomes they expand the breadth of use-[21].

2.8. Open Data Center Alliance (ODCA) Information as a Service (INFOaaS)

Figure 2-7 defines the tasks necessary to manage data by using information as a service and describes them in four stages i.e data sources and operation, data acquisition and distribution, integrates information platform and information services[23].

It reduces non-essential functionality so as reduce operational and infrastructure costs by identifying non-core systems and optimizes them. It provides organizations with flexibility increase, efficiency gain, quality gains and velocity gains.

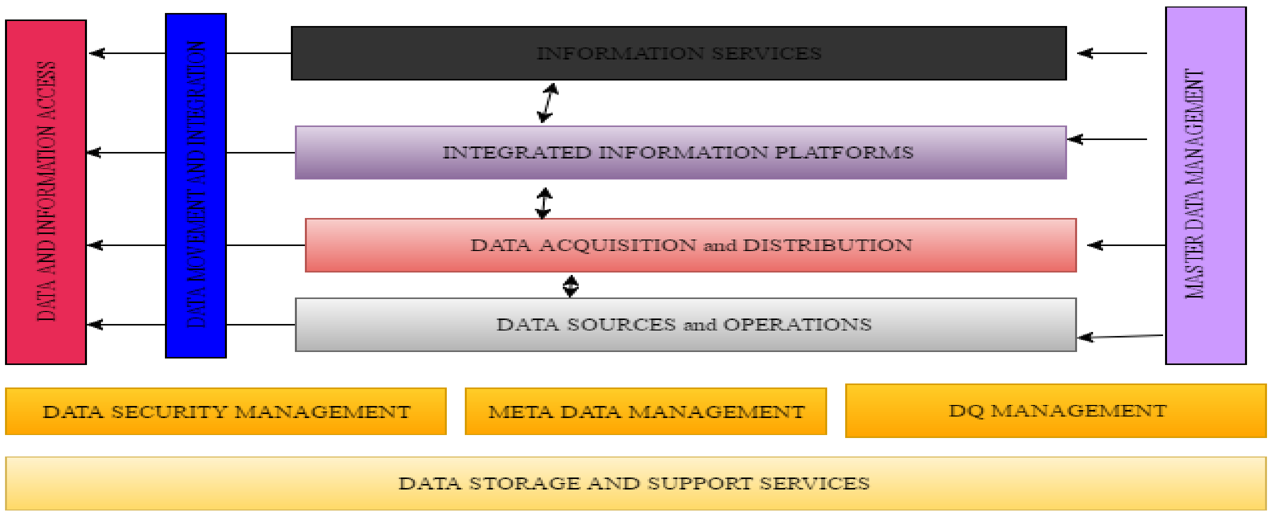

Figure 2-7: Open Data Centre Alliance [22]

2.9. Mobile cloud computing Architecture.

Data storage and data processing services in the cloud are provided to the mobile users by MCC, therefore it is a combination of mobile web and cloud computing [24].

Base stations connect mobile devices to mobile networks; establish control and functional interfaces between them. Information that is transmitted to the central processors that are connected to the servers providing mobile network services is requested by the mobile users.

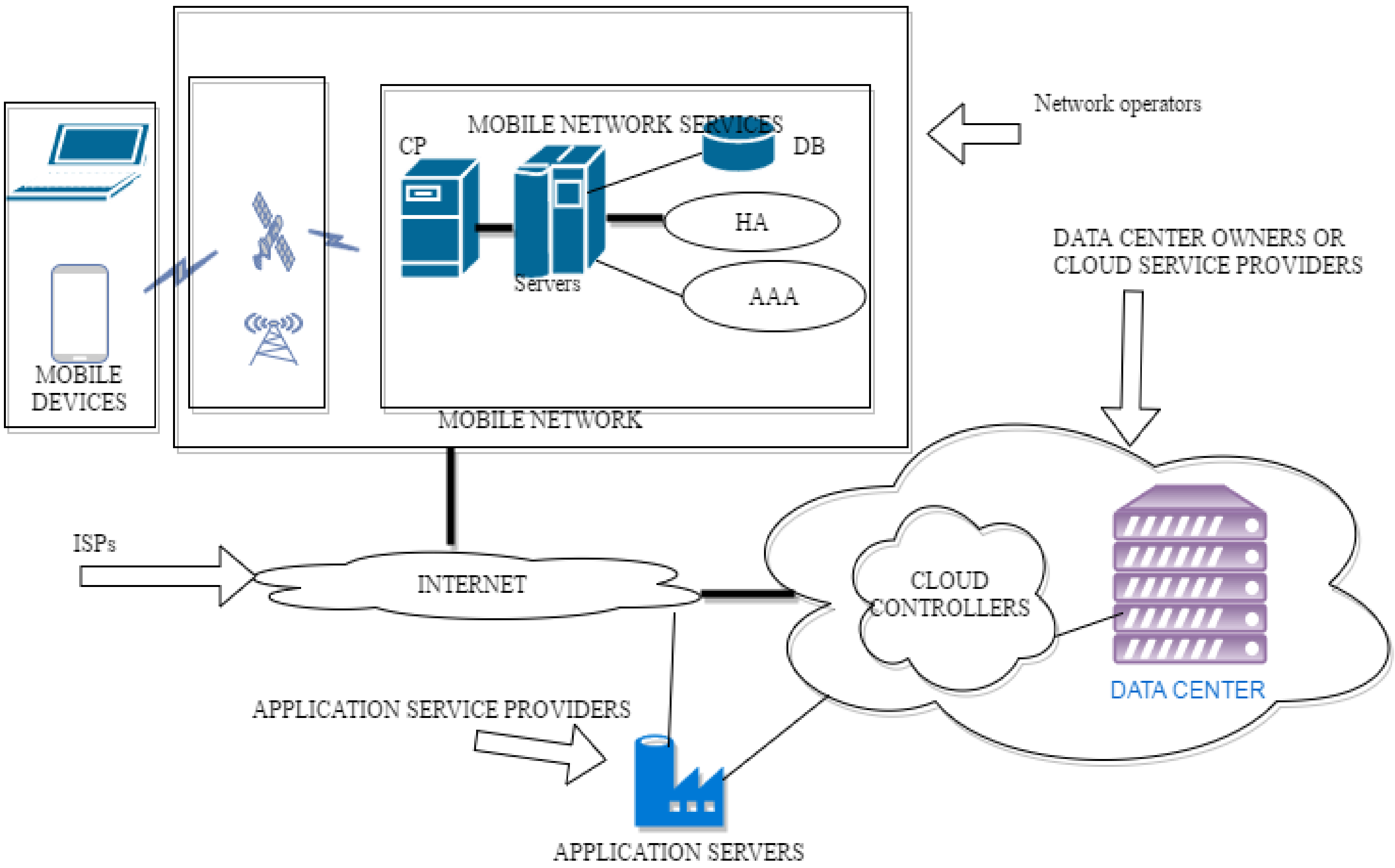

Figure 2-8: Mobile Cloud Computing [24]

Figure 2-8 illustrates how Mobile network operators provide services to mobile users as authentication, authorization and accounting (AAA) based on the home agent (HA) and subscriber's data stored in data bases, subscribers' requests are delivered to a cloud through the internet. Cloud controllers process the requests to provide mobile users with cloud services[25].Therefore the MCC architecture demonstrates the effectiveness of the cloud computing model for meeting Mobile user's requirements.

2.10. Summary

NIST focuses on Portability, interoperability and security issues in the cloud; The IBM deals with accessing data from anywhere while keeping data management in check. Oracle deals with information management data querry, and analysis while dealing with performance. Big Data ecosystem shows the broad view of the variety of data stores for different data structures, and approaches to analyze, store, recombine both structure and unstructured data. IoT reference architecture focuses on options for dealing with the massive amount of data that comes streaming in from connected devices. TMF is a standard architecture for handling data ingestion, data management, data analysis and real time stream processing being accessed in the big data repository which drastically improves high performance of the system and supports scalability of devices connected to it from different developers. ODCA defines the tasks necessary to manage data by using information as a service and describes them in four stages i.e data sources and operation, data acquisition and distribution, integrates information platform and information services. the MCC architecture demonstrates the effectiveness of the cloud computing model for meeting Mobile user's requirements.

It is worth mentioning that since BD, MCC& IoT are new emerging technologies, the related work is so limited and that which is available is not easy to access. There are no reviews for the concrete relationship of the related work of the three technologies.

Therefore the designed service level architecture for handling Big Data will meet the following requirements:

- ❖ It must support different platforms and data formats and protocols.
- ❖ It must be deployed in different environments.
- ❖ It must scale according to both data storage and processing purposes.
- ❖ It must provide a mechanism to support MCC users to access and retrieve big data while hiding the underlying database.

2.11. Approach used in research methodology

In research methodology, Gagster and Avgeriou is he proposed approach [26] which involves different steps that are used to design the reference architecture.

To structure the set of models Galster and Avgeriou [26] agree with the general recommendation within the software architecture literature to use the notion of views. According to the respective and

ISO standards for the design of software architectures, a view consists of one or several models that represent one or more aspects of the system particular set of stakeholder concerns.

2.12. Technologies to be used and supported by the architecture

2.12.1. Bluetooth

It's a useful short-range communications technology which has become very important in computing and many consumer electronic products, such as in smartphones. It is expected to be key for wearable e- products and covers a distance of 50m-150m.

The new Bluetooth Low-Energy (BLE) – or Bluetooth Smart, as it is now branded – is a significant protocol for IoT applications. Importantly, while it offers similar range to Bluetooth it has been designed to offer significantly reduced power consumption. Smart/BLE is not really designed for file transfer and is more suitable for small chunks of data. It has a major advantage certainly in a more personal device context over many competing technologies given its widespread integration in smartphones and many other mobile devices. According to the Bluetooth SIG, more than 90 percent of Bluetooth-enabled smartphones, including iOS, Android and Windows.

Devices that employ Bluetooth Smart features incorporate the Bluetooth Core Specification Version 4.0 (or higher – the latest is version 4.2 announced in late 2014) with a combined basic-data-rate and low-energy core configuration for a RF transceiver, baseband and protocol stack. Importantly, version 4.2 via its Internet Protocol Support Profile will allow Bluetooth Smart sensors to access the Internet directly via 6LoWPAN connectivity. This IP connectivity makes it possible to use existing IP infrastructure to manage Bluetooth Smart 'edge' devices[27].

2.12.2. Zigbee

ZigBee, like Bluetooth, has a large installed base of operation, although perhaps traditionally more in industrial settings. ZigBee PRO and ZigBee Remote Control (RF4CE), among other available ZigBee profiles, are based on the IEEE802.15.4 protocol, which is an industry-standard wireless networking technology operating at 2.4GHz targeting applications that require relatively infrequent data exchanges at low data-rates over a restricted area and within a 100m range.

ZigBee/RF4CE has some significant advantages in complex systems offering low-power operation, high security, robustness and high scalability with high node counts and is well positioned to take advantage of wireless control and sensor networks in M2M and IoT applications [28].

2.12.3. Z-Wave

Z-Wave is a low-power RF communications technology that is primarily designed for home automation for products such as lamp controllers and sensors among many others. Optimized for reliable and low-latency communication of small data packets with data rates up to 100kbit/s, it operates in the sub-1GHz band, with a coverage area of up to 30 Meters and is impervious to interference from WiFi and other wireless technologies in the 2.4-GHz range such as Bluetooth or ZigBee[29].

2.12.4. RFID

Radio frequency identification (RFID) is the wireless use of electromagnetic fields to identify objects. Usually you would install an active reader, or reading tags that contain a stored information mostly authentication replies. Experts call that an Active Reader Passive Tag (ARPT) system. Short range RFID is about 10cm, but long range can go up to 200m. What many do not know is that Léon Theremin invented the RFID as an espionage tool for the Soviet Union in 1945. An Active Reader Active Tag (ARAT) system uses active tags awoken with an interrogator signal from the active reader. Bands RFID runs on: 120–150 kHz (10cm), 3.56 MHz (10cm-1m), 433 MHz (1-100m), 865-868 MHz (Europe), 902-928 MHz (North America) (1-12m) [30].

2.12.5. 6LoWPAN

A key IP (Internet Protocol)-based technology is 6LowPAN (IPv6 Low-power wireless Personal Area Network). Rather than being an IoT application protocols technology like Bluetooth or ZigBee, 6LowPAN is a network protocol that defines encapsulation and header compression mechanisms. The standard has the freedom of frequency band and physical layer and can also be used across multiple communications platforms, including Ethernet, Wi-Fi, 802.15.4 and sub-1GHz ISM. A key attribute is the IPv6 (Internet Protocol version 6) stack, which has been a very important introduction in recent years to enable the IoT. IPv6 is the successor to IPv4 and offers approximately 5 x 10^{28}addresses for every person in the world, enabling any embedded object or device in the world to have its own unique IP address and connect to the Internet. Especially designed for home or building automation, for example, IPv6 provides a basic transport mechanism to produce complex control systems and to communicate with devices in a cost-effective manner via a low-power wireless network.

Designed to send IPv6 packets over IEEE802.15.4-based networks and implementing open IP standards including TCP, UDP, HTTP, COAP, MQTT, and websockets, the standard offers end-to-end addressable nodes, allowing a router to connect the network to IP. 6LowPAN is a mesh network that is robust, scalable and self-healing. Mesh router devices can route data destined for other devices, while hosts are able to sleep for long periods of time

2.12.6. Thread

A very new IP-based IPv6 networking protocol aimed at the home automation environment is Thread. Based on 6LowPAN, and also like it, it is not an IoT applications protocol like Bluetooth or ZigBee. However, from an application point of view, it is primarily designed as a complement to WiFi as it recognises that while WiFi is good for many consumer devices that it has limitations for use in a home automation setup.

It is a free protocol based on various standards including IEEE802.15.4 , IPv6 and 6LoWPAN, and offers a resilient IP-based solution for the IoT.

Thread supports a mesh network using IEEE802.15.4 radio transceivers and is capable of handling up to 250 nodes with high levels of authentication and encryption [31].

2.12.7. WiFi

WiFi connectivity is an obvious choice for many developers, especially given the pervasiveness of WiFi within the home environment within LANs. There is a wide existing WiFi infrastructure and it offers fast data transfer and the ability to handle high quantities of data.

- Standard: Based on 802.11n (most common usage in homes today)
- Frequencies: 2.4GHz and 5GHz bands
- Range: Approximately 50m
- Data Rates: 600 Mbps maximum, but 150-200Mbps is more typical, depending on channel frequency used and number of antennas (latest 802.11-ac standard should offer 500Mbps to 1Gbps)

2.12.8. Cellular

Any IoT application that requires operation over longer distances can take advantage of GSM/3G/4G cellular communication capabilities. While cellular is clearly capable of sending high quantities of data, especially for 4G, the expense and also power consumption will be too high for many applications, but it can be ideal for sensor-based low-bandwidth-data projects that will send very low amounts of data over the Internet.

Its standard is GSM/GPRS/EDGE (2G), UMTS/HSPA (3G), LTE (4G) at frequencies 900/1800/1900/2100MHz ranging 35km max for GSM; 200km max for HSPA ,with data rates (typical download): 35-170kps (GPRS), 120-384kbps (EDGE), 384Kbps-2Mbps (UMTS), 600kbps-10Mbps (HSPA), 3-10Mbps (LTE)

2.12.9. NFC

NFC (Near Field Communication) is a technology that enables simple and safe two-way interactions between electronic devices, and especially applicable for smartphones, allowing to handle big data using IOT and MCC to connect electronic devices. Essentially it extends the capability of contactless card technology and enables devices to share information at a distance that is less than 4cm.

2.12.10. Sigfox

It is a wide-range technology, which ranges between WiFi and cellular. It uses the ISM bands, which are free to use without the need to acquire licenses, to transmit data over a very narrow spectrum to and from connected objects. The idea for Sigfox is that for many M2M applications that run on a small battery and only requires low levels of data transfer.Sigfox uses a technology called Ultra Narrow Band (UNB) and is only designed to handle low data-transfer speeds of 10 to 1,000 bits per second while consuming only 50 microwatts at a range of 30-50km.

The network offers a robust, power-efficient and scalable network that can communicate with millions of battery-operated devices across areas of several square kilometres, making it suitable for various M2M applications that are expected to include smart meters, patient monitors, security devices, street lighting and environmental sensors.

2.12.11. Neul

Operates in the sub-1GHz band, Neul leverages very small slices of the TV White Space spectrum to deliver high scalability, high coverage, low power and low-cost wireless networks. The communications technology is called Weightless, which is a new wide-area wireless networking technology designed for the IoT that largely competes against existing GPRS, 3G, CDMA and LTE WAN solutions. Data rates can be anything from a few bits per second up to 100kbps over the same single link; and devices can consume as little as 20 to 30mA.

2.12.12. LoRaWAN

LoRaWAN targets wide-area network (WAN) applications is designed to provide low-power WANs with features specifically needed to support low-cost mobile secure bi-directional communication in IoT, M2M and smart city and industrial applications. Optimized for low-power consumption and supporting large networks with millions and millions of devices, data rates range from 0.3 kbps

2.13. Conclusion

In this Chapter, different related work has been reviewed so as to help with an understanding of why the research is needed and its from where the problem to be solved has been identified. Different techniques are used on how they developed their architectures. The research methodology to be used in this thesis will be partly of my own process but will follow Gagster and Avgeriou approaches. Various technologies to support and be used in the architecture have been identified and briefly described. The designed service level architecture in Chapter 4 will incorporate some of the referenced services but will be of our own design since it will integrate the big data, MCC and IOT different services and terminologies.

Chapter 3 shows various steps(a methodology) that will be undertaken and used during the actual design of the reference architecture to handle the big data.

Chapter 3 Research methodology

3.0. Introduction

In this thesis, a methodology of how to design a service level architecture for handling big data using mobile cloud computing and internet of things is presented and its according to Gagster and Avgeriou that the designed architecture is from the scratch. The real world related architectures will be valuable to help to complete the design task.

The service architecture for handling big data that is to be designed will address the issues of Interoperability, scalability, heterogeneity, availability and manageability among other things on different layers. The layered design will enable the developers and manufacturers to modify and integrate any layer according to the demand of the users' applications.

3.1. Methodology for this Research

While developing a big data service level architecture, it is important to keep system components their interaction, functionality and properties with concrete the demands of stakeholder requirements and business goals. The level of abstraction of the reference architecture and its concreteness of guidance need to be carefully balanced. Following a design method for reference architectures helps accomplishing that and the basis for the service level architecture to be well-grounded and valid as well as to provide relevance. It should be noted that the research about service level architectures and respective methodology is significantly rarer than that about concrete architectures.

3.2. Architectural requirement

The objective of our architecture is to simplify the development, configuration and deployment issues to enable ubiquity of WSNs, easier interfacing to other networks and the easier development of generic and more powerful applications using sensor data. To meet this objective, we define the following architecture requirements:

- ❖ It must be independent of particular node hardware, must handle a range of node functional capabilities and provide an extensible layered system able to handle the radio channel and environmental factors, within the required limits of power consumption.
- ❖ It must provide abstraction for the basic operations required of a sensor node and the services using it, which map easily to a range of heterogeneous devices and higher level services.
- ❖ It must clearly define the possible roles of nodes and any protocols must be sufficiently simple for low capability devices to participate. It is unreasonable to demand that all nodes have

equal functionality, as this limits the ability to handle more powerful nodes. Nodes will, however, require a minimum level of functionality, e.g. forwarding data to a neighbour.

- ❖ It must provide a consistent means to exchange sensor information independent of the underlying technology and provide specific support for the modelling of sensor data to allow integration into higher level systems. A sensor node should be able to advise other nodes and services of its sensing and platform capabilities.
- ❖ It must be able and allow the system to adapt as the network grows/changes or encounters other networks and support applications discovering and collaborating without a centralized coordination facility to handle small, static networks

3.3. Proposed design development process.

Step 1: Decide on the architecture type

Deciding on the characterization of a particular type of architecture provide guides on how to reach the design decisions and thereby helping to fix and reach to its purpose and to where it should be placed at.

Step 2: Select the design strategy

The design strategy is based on the existing architecture artefacts with the domain. It is thus practise driven rather than from the scratch and is marched with the architecture type.

The second step is to decide, if the reference architecture will be designed from scratch (research driven) or designed based on existing architecture artefacts within the domain (practice-driven).

The design strategy is marched with the architecture type chosen in step 1. Therefore, our selection of the design decision is the practice driven.

Step 3: Empirical acquisition of data

The use of comprehensive interviews or questionnaires will not be possible due to the nature of this thesis scope; hence, the reference architecture will mainly be based on the documentations and literature.

It will involve document study and content analysis of literature about ‘big data’, mobile cloud computing and Internet of things including existing architecture descriptions and academic research papers. A first result of the literature study is the establishment of requirements the resulting reference architecture will be based on. These architectural requirements are presented in this chapter.

Step 4: Construction of the service level architecture

After the data acquisition, the next architecture is constructed, which will be described in Chapter 4. Architecture consists of a set of models. Constructing the architecture therefore means to develop these models. In that sense a view targets a specific group of stakeholders and allows them to understand and analyze the system from their perspective filtering out elements of the architecture which are of no concern for that specific group.

Step 5: Enabling architecture with variability

Variability is to be inherent in the abstractness of the reference architecture. The aim is for Completeness regarding the functional components, so variability can be implemented by choosing the functionality required for a concrete architecture based on its requirements, while leaving unwanted functionality out.

Step 6: Evaluation of the service level architecture

Unfortunately it will not be possible to evaluate the service level architecture within a concrete project situation due to the scope of this work. However the completeness and correctness of the reference architecture in chapter 4 is mapped with the work done in literature review of the existing architectures described in research papers, industrial white papers and reports.

3.4. Conclusion

The mentioned steps above are the ones that are used in chapter 4 to design the proposed reference level architecture for handling big data using IOT and MCC. It is easy to use and understand since the design is not from the scratch and depends on existing artefacts of other architectures that are practice driven. Even though their applications and use are still limited due to lack of standard and common policies of developers and vendors, the proposed architecture will be presented in different conferences, seminars and in publications so that it may be adopted and chapter 4 will show why it must be used.

Chapter 4 Design of the big data architecture using MCC and IOT.

4.0. Introduction

With an estimated number of 50 billion devices that will be networked by 2020, specific attention must be paid to transportation, storage, access, and processing of the huge amount of data they will produce. Thanks to the recent development in technologies, IoT will be one of the main sources of big data, and Cloud will enable to store it for long time and to perform complex analyses on it. The ubiquity of mobile devices and sensor pervasiveness, indeed call for scalable computing platforms. Handling big data conveniently is a critical challenge, as the overall application performance is highly dependent on the properties of the data management service. Hence, following the NoSQL movement, both commercial and open source solutions adopt alternative database technologies for big data: time-series, key-value, document store, wide column stores, and graph databases. Unfortunately, no perfect data management solution exists for the Cloud to manage big data.

4.1. Relationship between IOT and MCC

IOT	MCC
1) Real things	1) Virtual resources
2) Sources of big data	2) Means to manage big data
3) Limited storage capabilities	3) Unlimited storage capabilities
4) Internet as a point of convergence	4) Internet for service delivery
5) Things placed everywhere	5) Resources usable from everywhere
6) Limited computational abilities	6) Virtually unlimited computational abilities

4.2. Interaction between BD, MCC&IOT

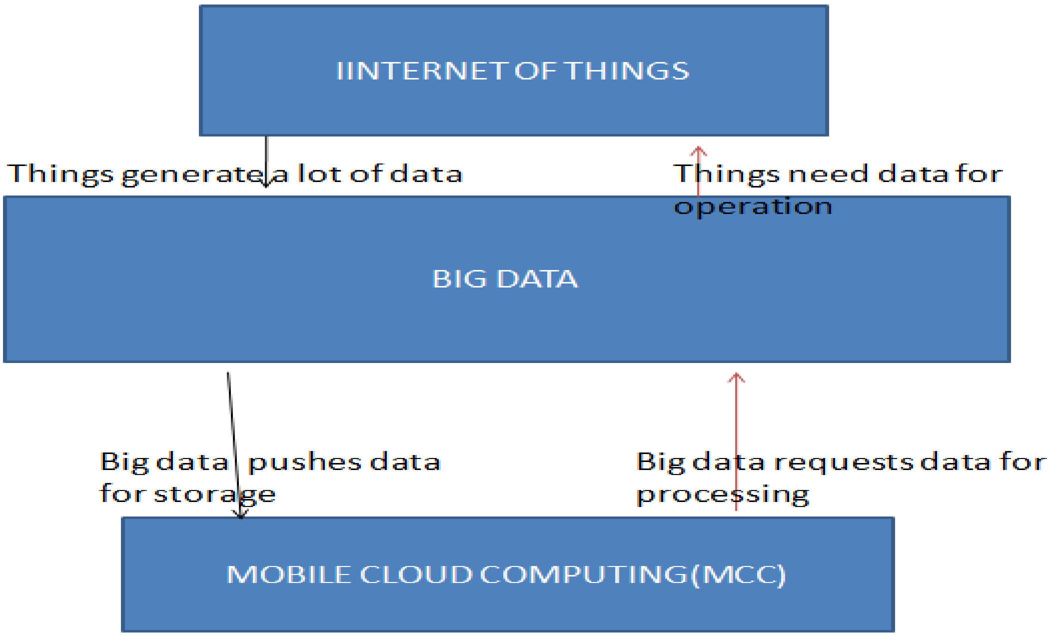

Figure: 4-1: Interaction between BD,MCC &IOT

Internet of things generate and produce data through the use of Actuators and sensors, however they have limited storage capacity and low processing power so they use the services of the Big Data system to store and process the data that will be stores in the cloud and accessed by mobile devices in various applications. It is also imperative to say that mobile devices that use data from the cloud computing will also need the storage and processing power of the big data and in the end they maybe termed as Internet of things. These three technologies are interdependent and they thus need to collaborate and interoperate so as to integrate their functionalities while communicating with efficiency.

4.3. Big data classifications

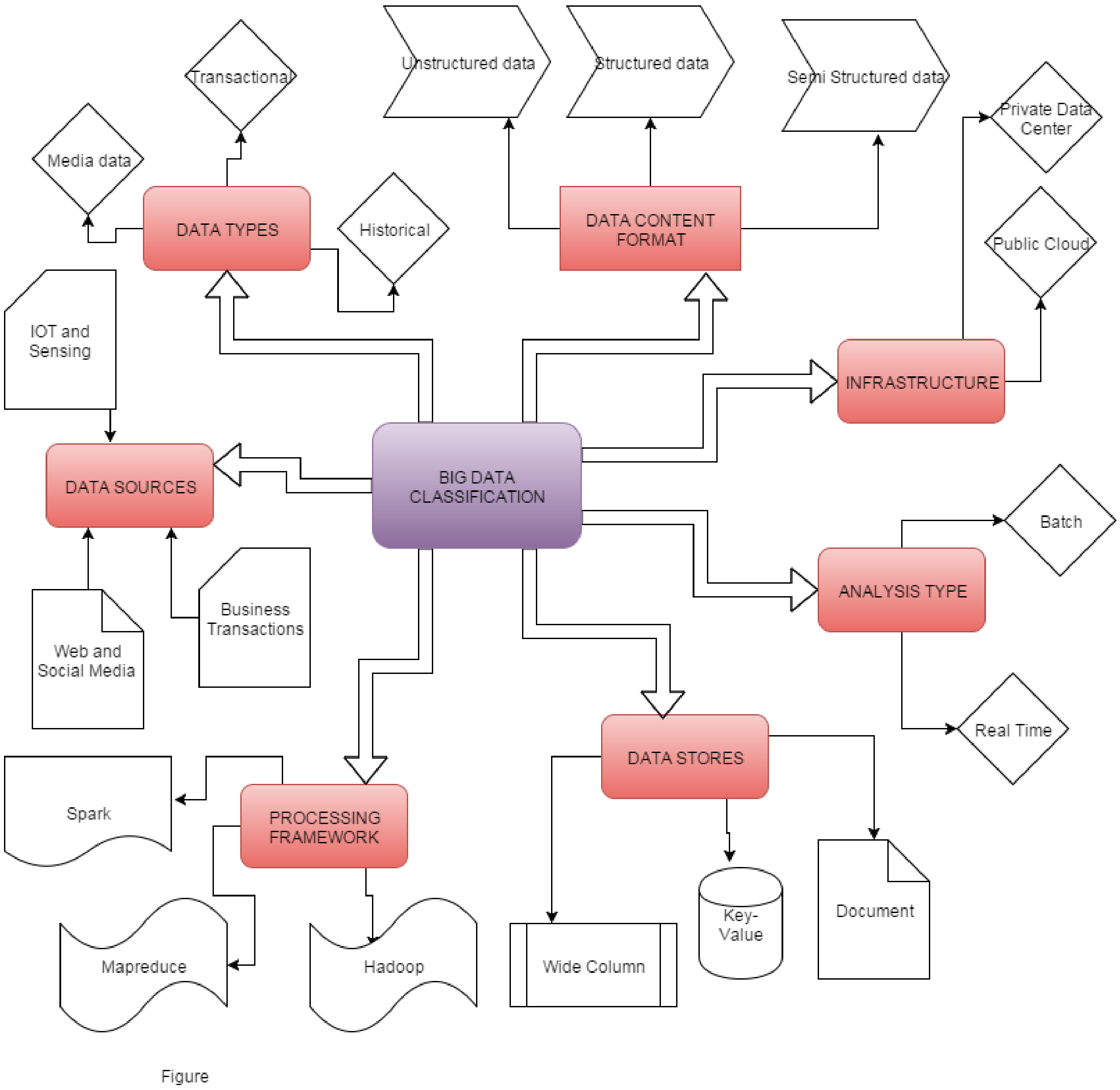

Figure 4-2: Big data classifications

4.3.1. Data Sources

4.3.1.1. Web Data & social media

Web pages, blogs and online articles are the sources of both structured and unstructured data that include text, videos and images.

Messaging services and status updates in social media are some of the data types from social interaction

4.3.1.2. Big transaction data

These are unstructured textural data that is generated by human doing business transactions eg insurance claims, call center records, transactions from credit cards. This data grows from massive amount of operations and transactions performed by different systems.

4.3.2. Data store:

After collection and conversion, data needs to be stored and archived. Facing the large amounts of data, distributed file storage systems and distributed databases are generally used to distribute the data to multiple storage nodes, and are also needed to provide mechanisms such as backup, security, access interfaces, and protocols.

4.3.2.1. Key Value Stores

In key value stores data is addressed by a unique key which is similar to dictionary or map. It provides very basic building blocks which have very predictable performance characteristics. It supports massive data storage with high concurrency. The query speed is higher than relational database.

4.3.2.2. Document stores

Document stores are similar to Key-value pairs but encapsulate key-value pairs in JSON or XML like format. Every document contains a unique "ID" within a collection of documents and can be identified explicitly. Within a document, keys have to be unique too. Document database are suitable for nested data objects and complex data structures. It offers multi attribute lookups on documents.

4.3.2.3. Wide column

Data is physically stored by data column by column in data bases. This kind of storage achieves higher compression rates due to the homogeneity within data. The advantages for read performance make wide column databases a very good fit for the analysis of data stores in the design of big data architecture.

4.3.3. Data Content Format

4.3.3.1. Structured data.

Data that reside in fixed fields. Examples of structured data include relational databases or data in spreadsheets. Contrast with semi-structured data and unstructured data.

4.3.3.2. Unstructured data.

Data that do not reside in fixed fields. Examples include free-form text (e.g., books, articles, body of e-mail messages), untagged audio, image and video data. Contrast with structured data and semi-structured data.

4.3.3.3. Semi-structured data.

Data that do not conform to fixed fields but contain tags and other markers to separate data elements. Examples of semi-structured data include XML or HTML-tagged text. Contrast with structured data and unstructured data.

4.3.4. Processing Framework

4.3.4.1. Hadoop

It is now a day default choice for analyzing large data set for batch processing. It has a large ecosystem of related tools which makes writing individual processing steps easier or orchestrates more complex jobs. Hadoop provide a collection of debugging and reporting tools and most of them are accessible through a web interface which make easy to track MapReduce job state and drill down the errors and warning log files.

4.3.4.2. MapReduce

MapReduce framework is the power house behind most of today's big data processing. It is a software framework that takes query over large data sets, divide it and run it in parallel over several machines. The core idea is that we write a map function that processes a key/value pair to generate a set of intermediate key/value pairs and we also write a reduce function that merges all intermediate values associated with the same intermediate key. We can simplify many real world problems using this model.

4.4. Proposed Big data architecture

4.4.1. Introduction

The Figure 4-3 represents the proposed architecture design for handling big data using MCC and IOT. The components and layers making it are explained. This architecture is unique because it integrates the three emerging technologies, BD,MCC&IoT, this is possible because they interdependent on each other and one cannot use one while ignoring the other.

The integration and collaboration of these emerging technologies accompanied with high security and manageability of resources and services, the designed architecture will enable high performance through efficiently allowing easy heterogeneity of various components and hence effectively achieving the interoperability of the services.

This architecture design is open to any technology, policies, standards and it will accommodate all various kinds of products and services from various audiences since it uses Open system interconnection protocols and follows all the International standards organisation's rules and regulations.

4.4.2. Devices

Different devices or things have to be interconnected using different networks. These devices may be powered by lower power as compared to the traditional existing ones that are so far connected using internet of things which may be classified as passive or active devices.

These devices have a small storage and processing power and are fitted with sensors and actuators such that they are identified on a network. These devices have a unique identifier that they get though Internet Protocol addresses (IP). Some still do use IPv4, but since more and more devices are to be connected, IPv6 has been adopted and will be possible to address all the things (devices) that will be needed to be connected using this designed architecture.

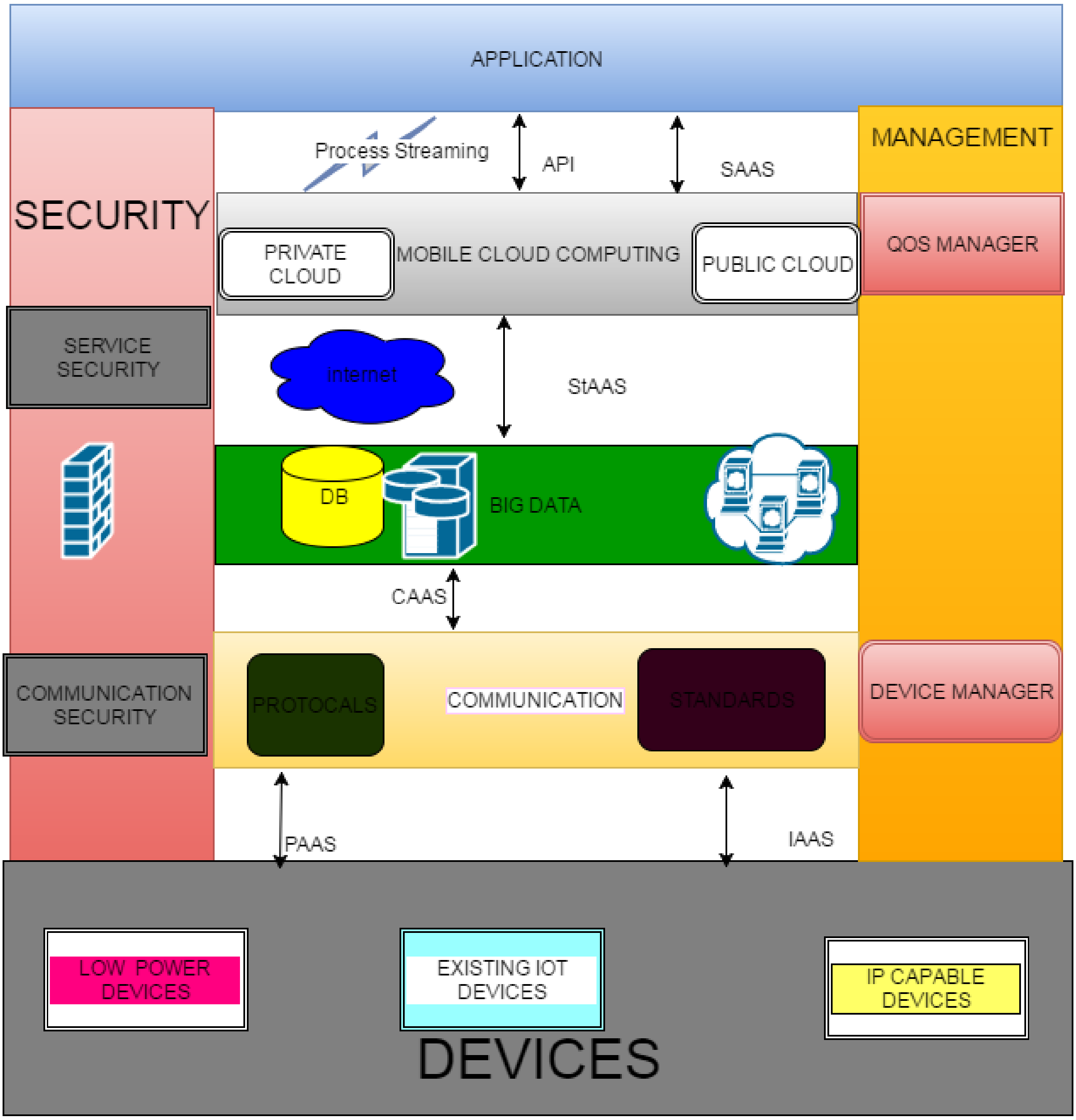

Figure 4-3: A service level Big data architecture using MCC and IOT

4.4.3. Communication

The *Communication Functionality Group* (CFG) aims to tackle all communication needs of IoT-A compliant systems. Both data plane and control plane are taken into account. The main idea is to have a slicing in functional components abstracting from the reference model layer itself being almost orthogonal, since a lot of functionalities can be achieved at different layers. The best way to understand this functional group is as the sum of his functional components. Hence, the CFG enables addressing and routes propagation in order to enable various communication modes and bypassing the limitation of hop-to-hop communication. The CFG ensures as well reliable communication and flow control, and even expands it to multiple flows, enabling in this way QoS enforcement. The CFG ensures also energy optimization exposing functions dealing directly with the radio control but also application level duty cycles. Finally, the CFG enables bridging among different networks, allowing Devices to perform as a network entry point implementing forwarding, filtering, connection tracking and packets aggregation functions. All those functionalities are as well supported by an error detection implemented by this FG.

4.4.3.1. Communication model

The communication model aims at defining the main communication paradigms for connecting entities, as defined in the domain model. We provide a reference communication stack, together with insights about the main interactions among the actors in the domain model. We developed propose a communication stack similar to the ISO OSI 7-layer model for networks, mapping the needed features of the domain model onto communication paradigms. We also describe how communication schemes can be applied to different types of networks in IoT.

4.4.3.2. Communication stack

This model aims at mimicking the ISO/OSI stack, but it puts the focus on IoT systems requirements and characteristics.

IoT communication stack.

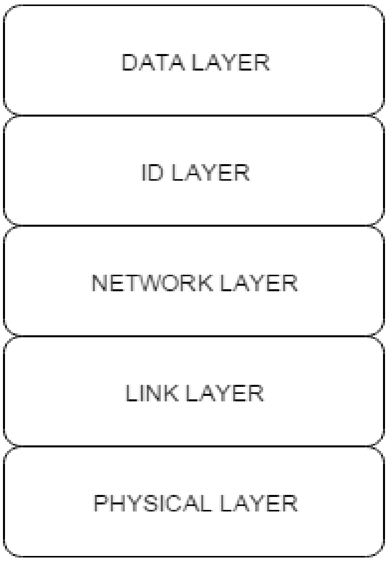

Figure 4-4: Communication stack

The model, as depicted in Figure 4.4 stresses the relevance of the layers above the link layer. In fact, the main strength of this communication model is the interoperability between heterogeneous networks.

In the following, details of the different layers are provided; viz. how each of them is designed to satisfy one or more particular requirements of the reference model.

Physical layer: The physical layer remains unchanged from the OSI definition. This is necessary in order to neither exclude any available technology, nor to prevent emerging solutions from being integrated into the reference model. The convergence of the different solutions taking part in the communication stack will be managed in the upper layer.

Link layer: In order to address the heterogeneousness of networking technologies represented in the IoT field, the link layer requires special attention. In fact, most networks implement similar, but customized communication schemes and security solutions. In order for IoT systems to achieve full interoperability, as well as the support of heterogeneous technologies and a comprehensive security framework, this layer must allow for diversity. But, at the same time, it needs to provide upper layers with uniform capabilities and interfaces.

Network layer: Here, again, the layer provides the same functionalities as the correspondent OSI stack. However, in order to support global manageability, interoperability, and scalability, this layer needs to provide a common communication paradigm for every possible networking solution.

ID layer: The *Virtual-Entity IDentifier*(VE-ID), split from the locator, is the centre of the first convergence point in the communication stack, i.e. the ID layer. Leveraging on uniform interfaces provided by the link layers, the ID Layer allows for a common resolution framework for the IoT. Also, security, authentication, and high-end services will exploit this layer for providing uniform addressing to the many different devices and technologies in IoT networks.

Data layer: at the top of the communication stack, the entry point is the data layer. A high-level description of the data pertinent to IoT .

Data link layer incorporates **End-to-end layer** which takes care of translation functionalities, proxies/gateways support and of tuning configuration parameters when the communication crosses different networking environments. By building on top of the ID and the network layers, the end-to-end layer provides the final building block for achieving a global M2M communication model.

4.4.4. Cloud computing deployment models

Cloud computing can also be divided on the basis of deployment, level of access, of the cloud services.

4.4.4.1. Public cloud

Public clouds are available to the general public, or large organizations, and are owned by a third party organization that offers the cloud service. Google, Amazon and Microsoft are examples of public cloud vendors who offer their services to the general public. Data created and submitted by customers are usually stored on the servers of the third party vendor.

4.4.4.2. Private cloud

"The cloud infrastructure is operated solely for an organization. It may be managed by the Organization or a third party and may exist on premise or off premise." The cloud infrastructure is accessed only by the members of the organization and/or by granted third parties. The purpose is not to offer cloud services to the general public but to use it within the organization. For example an enterprise that wants to make customer data available to their different stores.

4.4.4.3. Hybrid cloud

Hybrid cloud infrastructure is a composition of two or more clouds that are unique entities but at the same time are bound together by standardized or proprietary technology that enables data and application portability. For example, an enterprise that has their HR and CRM applications in a public cloud like Saleforces.com, but then have confidential data in their own private cloud.

4.4.4.4. Community cloud

"The cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). The idea is that the costs are spread on several organizations that all are in need of the same services.

4.4.5. Application Mobility

Moving an application between hosts and its execution will require a mobile device to access a cloud computing provider which exposes Big data resources. Applications will migrate from big data storages in the cloud computing to mobile device to which the user has an immediate access.

4.4.5.1. Stream processing.

Technologies designed to process large real-time streams of event data. Stream processing enables applications such as algorithmic trading in financial services, RFID event processing applications, fraud detection, process monitoring, and location-based services in telecommunications also known as event stream processing.

4.4.5.2. Software as a Service (SaaS)

Its how the users of mobile cloud computing will be allowed to access the applications provided by the big data through client interfaces like web browsers or program interfaces.

The software a service-model incorporates the mobile cloud provider installing and maintaining software within the cloud and users operating the software from their cloud clients over the Internet (or Intranet).

At this level the user does not control or manage the underlying infrastructures such as as network, servers, storage or operating systems.

The users' client devices do not need installation of any application-specific software, meaning all cloud applications run on the server in the cloud. SaaS is scalable and server system admin may load the applications on a number of servers. .

4.4.5.3. Platform as a Service (PaaS)

Platform as a Service (PaaS) is all about bringing applications and services to the cloud. The capability given to the developers to deploy onto the architecture their services, devices and tools produced. The user will have the control of the open deployed applications. It provides them a platform containing the whole technology stack to run applications and services supporting all the typical cloud characteristics like On-Demand Self-Service, Rapid Elasticity, Measured Service, Resource Pooling etc. In a layering model PaaS can be seen as a (middleware, glue) layer between Infrastructure (IaaS) and Software- and Service offerings for end-users (SaaS).

4.4.5.4. Infrastructure as a Service (IaaS)

Infrastructure as a service is virtualizing all the physical hardware (all servers, networks, storage and system management) are employed in the designed architecture. Companies pay a fee (monthly or annually) to run virtual servers, networks and storage from the cloud which will diminish the requirement for a data centre, environment setting and maintaining hardware at the local level.

4.4.5.5. Storage as a Service (StaaS)

Storage as a service provides and delivers virtualized storage on demand. All the data produced by IOT and processed by the Big data need to be stored in the cloud so that they maybe accessed in real time by the mobile devices.

Therefore storage as a service will be needed to provide data back-up, disaster recovery, security and high availability such that efficiency is realized consequently improving the performance of the designed architecture.

4.4.5.6. Collaboration as a Service (CaaS)

Collaboration is critical in this designed architecture since it involves communication at each stage of the layers throughout all the components and devices connected. CaaS helps in integration of all services and supports various functions in relation to Big data, IOT and MCC that lead to scalability for ever increasing resources.

4.4.6. Management

Big data and MCC management may be described at all levels of the architecture, with a unified management interface, both the developers and users may achieve data portability and service interoperability hence providing a platform to be used by different providers, manufacturers and users.

Provider and user management, inventory management, contract management, resource changing, rapid provisioning , SLA management , monitoring and reporting are some of the functionalities performed at the management levels.

4.4.7. Standards & Protocols

Standards should be designed to support various applications and address common requirements from all users, developers, vendors and manufacturers. It is only possible to develop standardized data models if a consensus involving all the stakeholders is reached. Common protocols, services and interfaces should be emphasized and should be cross cutting and open at all levels of the architecture.

Standards required should be bidirectional in both communication and information exchange such that different environments, mobile cloud computing entities and different big data providers are supported.

Standardization will support heterogeneity, scalability, interoperability, management and security of all devices, big data and MCC elements through set guidelines and policies at each level of the proposed architecture.

Protocols are rules and regulations set to be followed and accepted. In this designed architecture, the protocols to be used and adopted are like those of OSI-ISO (since it is an open architecture) as agreed upon by different body standards and should be able to accommodate any new immerging protocols.

4.4.8. Security

Security is a cross cutting aspect of the entire architecture, it ranges from all he physical security to application security. All the relevant actors are concerned with security requirements such as confidentiality, identity management, authorization, authentication integrity, security monitoring availability security policy management, incident response.

At each level of the entire life cycle of the architecture, security responsibility must be shared and thus adequate protection will be realized.

Finally, the Security function enables secure communications between peers by managing the establishment of integrity and confidentiality features between two entities lacking initial knowledge of each other.

4.5. Performance of the designed architecture

The designed architecture for handling big data using IOT and MCC will meet input and out bottlenecks because it is data intensive (handles different huge amounts of data from different applications).

The architecture integrates the emerging new technologies by allowing easy collaboration of different services thus allowing the interoperability of different devices and heterogeneity of different huge amount of data being produced.

It is a good design since it meets most of the designed standards, protocols and policies that over- sea communications hence its targeted audience would find it convenient to adopt and use it in their business plans

4.6. Conclusion

In this chapter, the big data architecture designed represents the relationship between IOT and MCC that will be used to handle the classified Big Data. The proposed design of the Big Data architecture has been developed by following the design development methods and will handle and accommodate different innovative technologies mentioned in Chapter 3. A communication model describing how services will be collaborating at each level is well described and each component developed is well defined which will lead to the integration of Big Data, MCC and IOT.

Chapter 5 Conclusion and Recommendations

5.1. Conclusion

A service level architecture for handling Big data using Mobile Cloud Computing has been designed.

The integration of Big Data, Mobile Cloud Computing and IOT is achieved since the architecture shows how they will be collaborating and the services they do provide is well defined at each level of their communication.

This architecture is specifically intended to be used by producers of different devices such that once those devices are connected to different types of networks on the internet, the generated data which is very huge will be managed and stored in the cloud and the mobile devices will access the stored data.

It is worth observing that once such architecture is adopted, different producers and vendors will have a common platform for their products and hence interoperability and Heterogeneity of them will be possible. As the services run throughout the architecture, efficiency and performance through management, storage and security of generated processed data will be achieved.

Standards and guideline set and achieved through the universal addressing and standardization will facilitate easy integration of Big Data, MCC and IOT.

5.2. Recommendations

- The architecture will be adoptable and easy to use since different layers define different functions thus allowing different users and producers to bring in their products with minimal costs through the use lower power consuming technologies.
- The relationship amongst BD,MCC and IOT is an ever increasing dynamic and complicated, its worth noting that this designed reference architecture will not meet all the targeted user preferences and therefore its an open architecture that will accommodate improvements and other technological updates.
- Security efforts must be put into a place because the architecture allows everyone to connect since it is an open architecture therefore product Producers must be authenticated.

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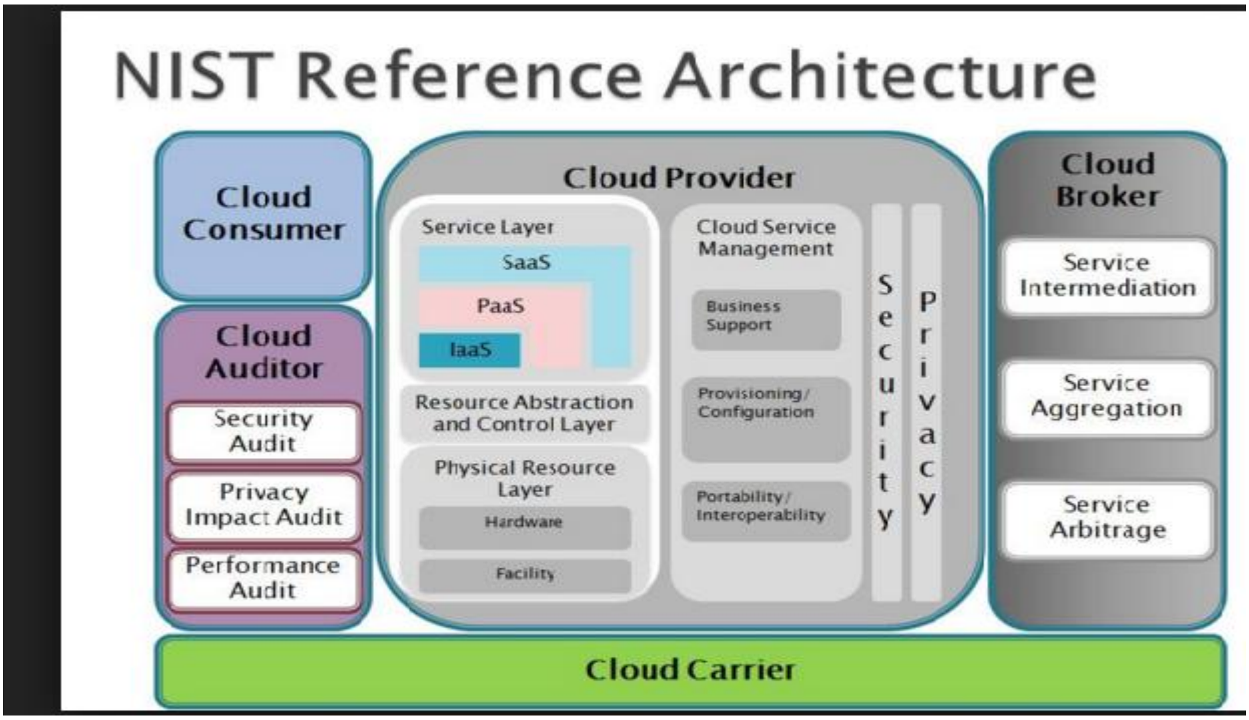
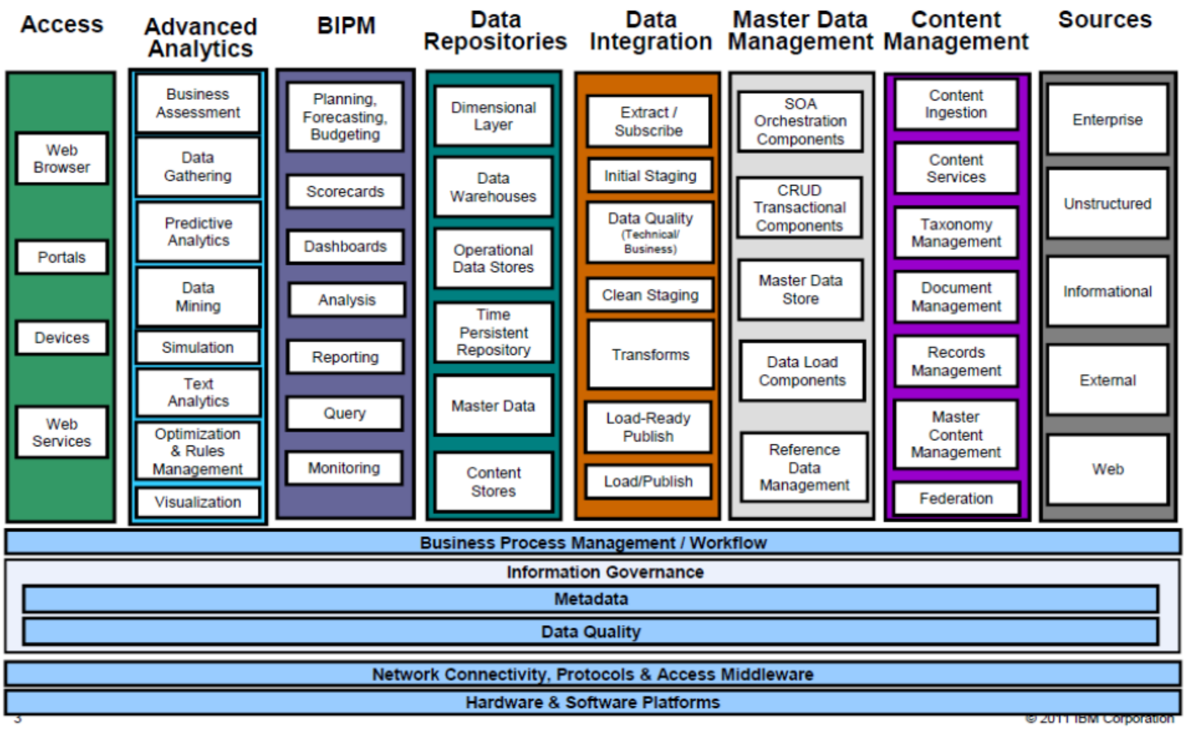
APPENDIX

The following are the architecture designs that were referenced too.

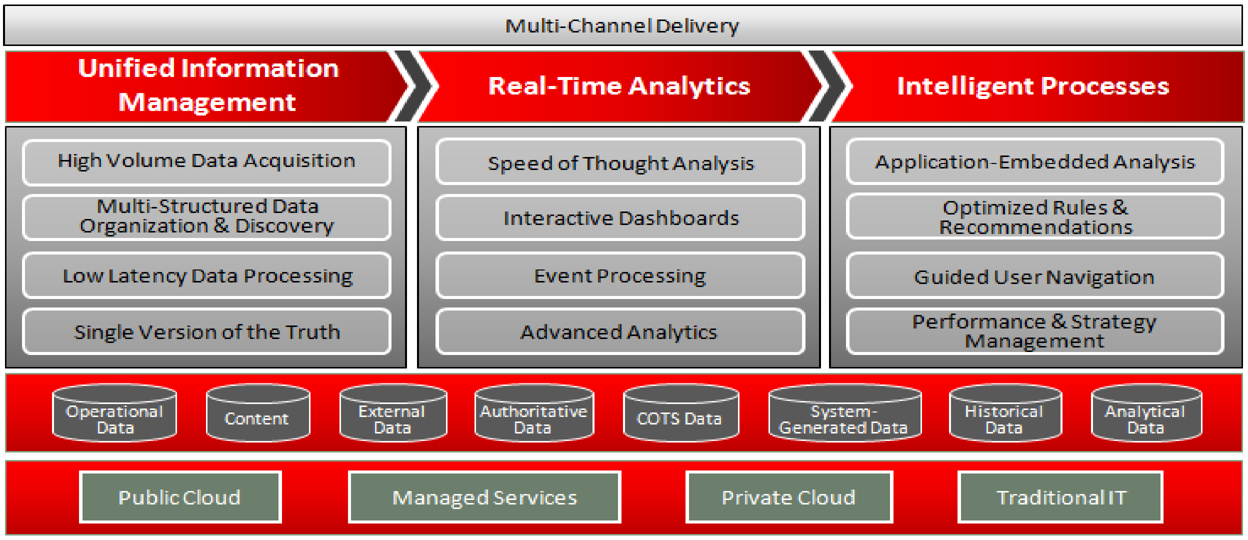
2.1 NIST reference Architecture



2.2 The IBM Business Analytics and Optimization Reference Architecture

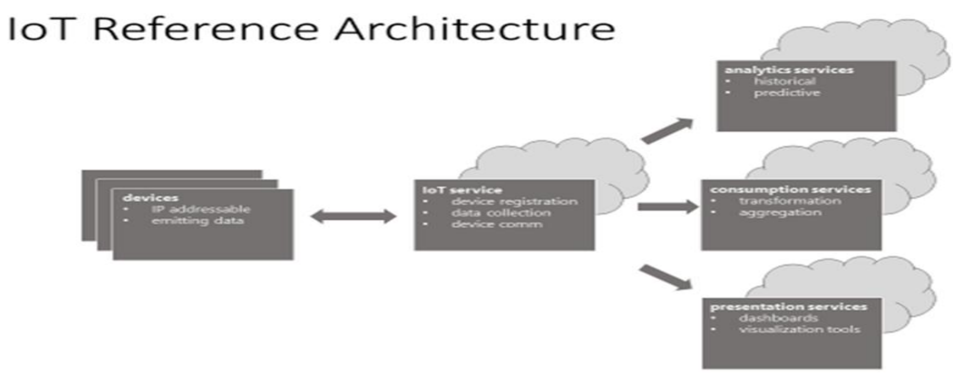


2.3 Oracle Big Data Reference Architecture.

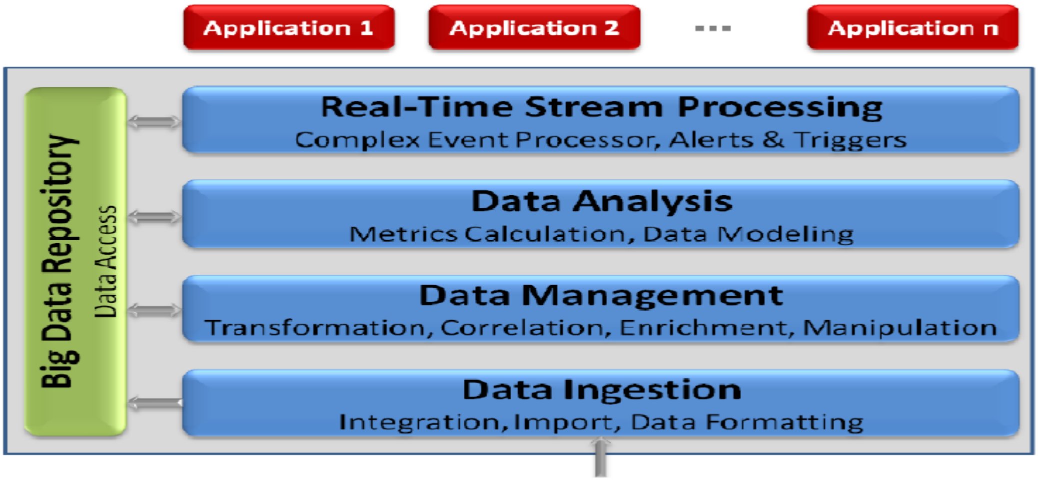


2.4 Big data ecosystem architecture

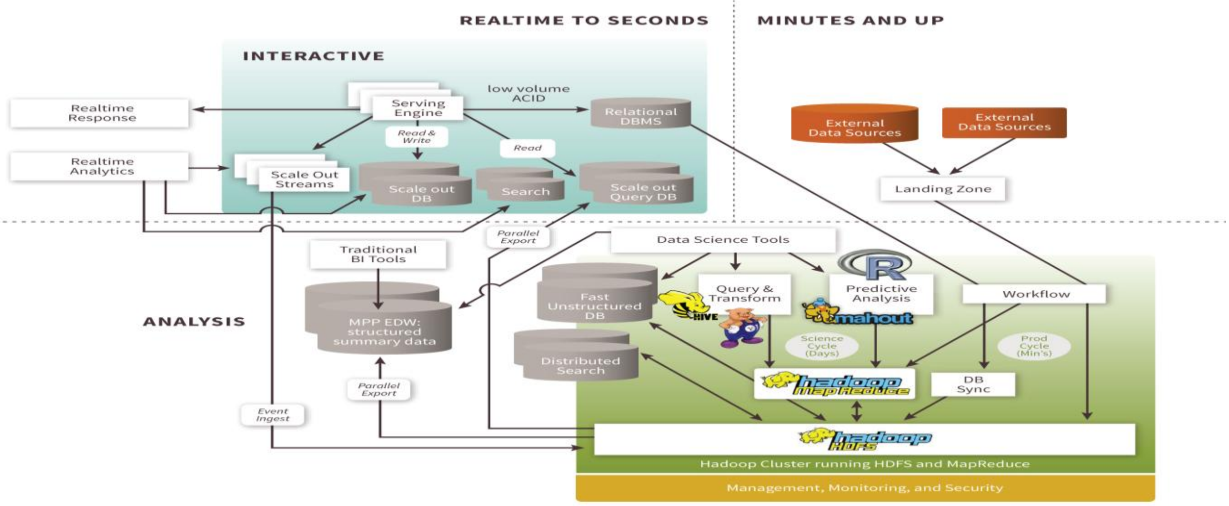
2.5 THE REFERENCE ARCHITECTURE



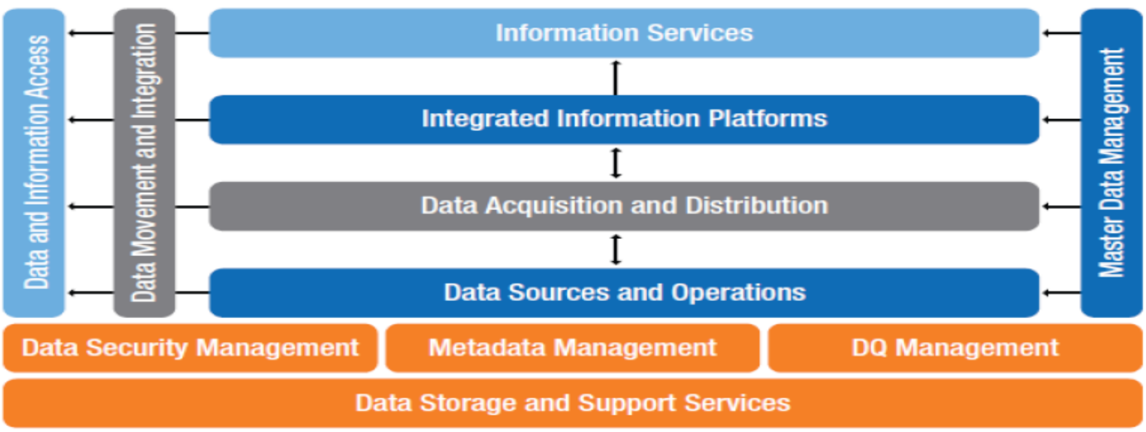
2.6 TMF Big Data Analytics Reference Architecture



2.7 Big Data Reference Architecture



2.8 Open Data Center Alliance (ODCA) Information as a Service (INFOaaS)



2.9 Mobile cloud computing Architecture.

MCC Architecture