Internet of Things and Integration with Cloud Computing

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Abstract- A fundamental understanding of the Internet of Things is that the data collection landscape has changed dramatically. Initially, ingested data in devices and storage caches were completely within the walls of the IT data center. At first, those walls gradually broke down as people started working from homes on their laptop and mobile devices which are connected to enterprises. Now we are seeing an explosion of devices in the field that need to connect and share data with the organizations. These devices, or things, need to share data with the same quality and performance regardless of whether they are in a remote corner of the world or in a metropolitan area. Enterprise data centers can't be everywhere. Thus, the Internet of Things is the primary application for cloud computing. Cloud computing and Internet of Things are two very different technologies that are both already part of our day to day life. Their adoption and use are expected to be more and more pervasive, making them important components of the Future Internet. A novel paradigm where Cloud and IoT are merged together is foreseen as disruptive and as an enabler of a large number of application scenarios. This paper provides a brief overview of IoT, importance of reference model for IoT, challenges faced by IoT and IoT and cloud convergence to resolve those challenges.

I. INTRODUCTION

IoT is simply the network of interconnected things or devices which are embedded with sensors, software, network connectivity and necessary electronics that enables them to collect and exchange data making them responsive. It is essentially an architectural framework which allows integration and data exchange between the physical world and computer systems over existing network infrastructure. Many people mistakenly think of IoT as an independent technology. Interestingly, internet of things is being enabled by the presence of other independent technologies which make fundamental components of IoT. [1]

The fundamental components that make internet of things a reality are:

- Hardware-Making physical objects responsive and giving them capability to retrieve data and respond to instructions
- Software-Enabling the data collection, storage, processing, manipulating and instructing.
- Communication Infrastructure- Most important of all is the communication infrastructure which consists of protocols and technologies which enable two physical objects to exchange data and thus communicate with each other.

II. BIRTH OF IOT

Though the term Internet of Things is 16 years old, the actual idea of connected devices had been around longer, at least since the 70s. Earlier, the idea was often called "embedded internet" or "pervasive computing". But the actual term "Internet of Things" was coined by Kevin Ashton in 1999 during his work at Procter&Gamble. Ashton who was working in supply chain optimization, wanted to attract senior management's attention to a new exciting technology called RFID. Because the internet was the hottest new trend in 1999, he called his presentation "Internet of Things".

Some of the milestones in the evolution of the mashing of the physical with the digital: -

- In January 13, 1946, the 2-Way Wrist Radio, worn as a wristwatch by Dick Tracy and members of the police force, makes its first appearance and becomes one of the comic strip's most recognizable icons.

- In 1949, the bar code is conceived when 27-year-olds Norman Joseph Woodland draws four lines in the sand on a Miami beach. Woodland, who later became an IBM engineer, received the first patent for a linear bar code in 1952. More than twenty years later, another IBMer, George Laurer, was one of those primarily responsible for refining the idea for use by supermarkets.
- In 1955, Edward O. Thorp conceives of the first wearable computer, a cigarette pack-sized analog device, used for the sole purpose of predicting roulette wheels.
- In October 4, 1960 Morton Heilig receives a patent for the first-ever head-mounted display.
- In 1967, Hubert Upton invents an analog wearable computer with eyeglass-mounted display to aid in lip reading.
- In October 29, 1969, the first message is sent over the ARPANET, the predecessor of the Internet.
- In June 26, 1974, a Universal Product Code (UPC) label is used to ring up purchases at a supermarket for the first time.
- In 1977, CC Collins develops an aid to the blind, a five-pound wearable with a head-mounted camera that converted images into a tactile grid on a vest.
- In early 1980s, members of the Carnegie-Mellon Computer Science department install micro-switches in the Coke vending machine and connect them to the PDP-10 departmental computer so they could see on their computer terminals how many bottles were present in the machine and whether they were cold or not.
- In 1990, Olivetti develops an active badge system, using infrared signals to communicate a person's location.
- In September 1991, Xerox PARC's Mark Weiser publishes "The Computer in the 21st Century" in Scientific American, using the terms "ubiquitous computing" and "embodied virtuality" to describe his vision of how "specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence."
- In 1993, MIT's Thad Starner starts using a specially-rigged computer and heads-up display as a wearable. [2]

III. IOT REFERENCE MODEL

Network, compute, application, and data management architectures that are IoT-ready require a different communication and processing model. Today, there is not a standard way of understanding or describing these models for the IoT. As a result, the lines are blurred between IoT devices and systems and non-IoT devices and systems. The fact is, not every network is an IoT network. Nor does it need to be. And not every application is an IoT application. In general, when data is generated under the control of machines or equipment and sent across a network, it is probably an IoT system. But in the IoT, even generalizations may be inappropriate. There may be many, many exceptions. As a result, the reference model:

- Simplifies: It helps break down complex systems so that each part is more understandable.
- Clarifies: It provides additional information to precisely identify levels of the IoT and to establish common terminology.
- Identifies: It identifies where specific types of processing are optimized across different parts of the system.
- Standardizes: It provides a first step in enabling vendors to create IoT products that work with each other.
- Organizes: It makes the IoT real and approachable, instead of simply conceptual.

A. Level 1: Physical Devices and Controllers

The IoT Reference Model starts with Level 1: physical devices and controllers that might control multiple devices. These are the "things" in the IoT, and they include a wide range of endpoint devices that send and receive information. Devices are diverse, and there are no rules about size, location, form factor, or origin. Some devices will be the size of a silicon chip. Some will be as large as vehicles. The IoT must support the entire range. Dozens or hundreds of equipment manufacturers will produce IoT devices.

B. Level 2 : Connectivity

Communications and connectivity are concentrated in one level—Level 2. The most important function of Level 2 is reliable, timely information transmission. This includes transmissions:

- Between devices (Level 1) and the network
- Across networks
- Between the network (Level 2) and low-level information processing occurring at Level 3

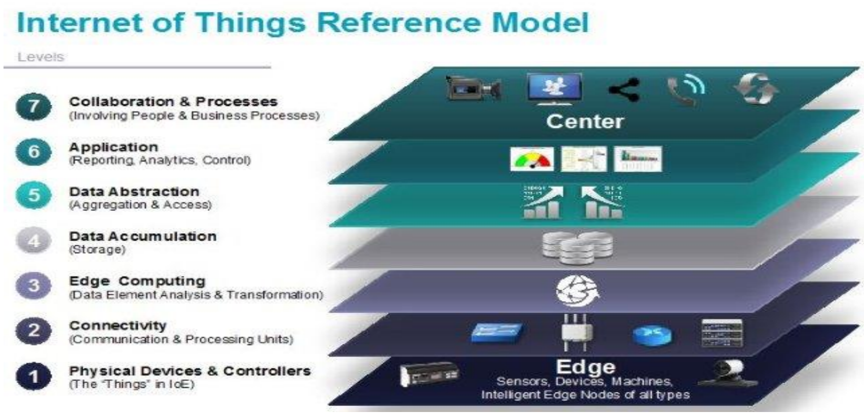

Figure 1. IOT Reference Model

C. Level 3 : Edge (Fog) Computing

The functions of Level 3 are driven by the need to convert network data flows into information that is suitable for storage and higher level processing at Level 4 (data accumulation). This means that Level 3 activities focus on high-volume data analysis and transformation. For example, a Level 1 sensor device might generate data samples multiple times per second, 24 hours a day, 365 days a year. A basic tenet of the IoT Reference Model is that the most intelligent system initiates information processing as early and as close to the edge of the network as possible. This is sometimes referred to as fog computing. Level 3 is where this occurs. Level 3 processing can encompass many examples, such as:

- Evaluation: Evaluating data for criteria as to whether it should be processed at a higher level
- Formatting: Reformatting data for consistent higher-level processing
- Expanding/decoding: Handling cryptic data with additional context.
- Distillation/reduction: Reducing and/or summarizing data to minimize the impact of data and traffic on the network and higher-level processing systems
- Assessment: Determining whether data represents a threshold or alert; this could include redirecting data to additional destinations.

D. Level 4 : Data Accumulation

Networking systems are built to reliably move data. Prior to Level 4, data is moving through the network at the rate and organization determined by the devices generating the data. The model is event driven. At Level 4, Data Accumulation, data in motion is converted to data at rest. Level 4 determines:

- If data is of interest to higher levels: If so, Level 4 processing is the first level that is configured to serve the specific needs of a higher level.
- If data must be persisted.
- The type of storage needed.
- If data is organized properly.
- If data must be recombined or recomputed.

As Level 4 captures data and puts it at rest, it is now usable by applications on a non-real-time basis. Applications access the data when necessary. In short, Level 4 converts event-based data to query-based processing.

E. Level 5 : Data Abstraction

IoT systems will need to scale to a corporate or even global level and will require multiple storage systems to accommodate IoT device data and data from traditional enterprise ERP, HRMS, CRM, and other systems. The data abstraction functions of Level 5 are focused on rendering data and its storage in ways that enable developing simpler, performance-enhanced applications. With multiple devices generating data, there are many reasons why this data may not land in the same data storage:

- There might be too much data to put in one place.
- Moving data into a database might consume too much processing power, so that retrieving it must be separated from the data generation process.
- Devices might be geographically separated, and processing is optimized locally.
- Levels 3 and 4 might separate “continuous streams of raw data” from “data that represents an event.” Data storage for streaming data may be a big data system, such as Hadoop. Storage for event data may be a relational database management system (RDBMS) with faster query times.
- Different kinds of data processing might be required.

The data abstraction level must process many different things. These include:

- Reconciling multiple data formats from different sources
- Assuring consistent semantics of data across sources
- Confirming that data is complete to the higher-level application
- Consolidating data into one place or providing access to multiple data stores through data virtualization
- Protecting data with appropriate authentication and authorization
- Normalizing or denormalizing and indexing data to provide fast application access.

F. Level 6 : Application

Level 6 is the application level, where information interpretation occurs. Software at this level interacts with Level 5 and data at rest, so it does not have to operate at network speeds. The IoT Reference Model does not strictly define an application. Applications vary based on vertical markets, the nature of device data, and business needs. For example, some applications will focus on monitoring device data. Some will focus on controlling devices. Some will combine device and non-device data. Monitoring and control applications represent many different application models, programming patterns, and software stacks, leading to discussions of operating systems, mobility, application servers, hypervisors, multi-threading, multi-tenancy, etc.

G. Collaboration and Processes

The IoT system, and the information it creates, is of little value unless it yields action, which often requires people and processes. Applications execute business logic to empower people. People use applications and associated data for their specific needs. Often, multiple people use the same application for a range of different purposes. So the objective is not the application—it is to empower people to do their work better. Applications (Level 6) give business people the right data, at the right time, so they can do the right thing. But frequently, the action needed requires more than one person. People must be able to communicate and collaborate, sometimes using the traditional Internet, to make the IoT useful. Communication and collaboration often requires multiple steps. And it usually transcends multiple applications.

IV. IOT CHALLENGES

A. Lack of Security

As massive networks of systems come online, these systems need to communicate with each other and with the enterprise, often over vast distances. Both the systems and the communications need to be secure, or millions of dollars' worth of assets are put at risk. One of the most prevalent examples of the need for security is the smart grid, which is on the leading edge of the IoT. As information on the grid becomes more accessible, so does the damage a security breach can inflict.

B. Scaling

Early adopters of Internet of Things products and technologies in business environments have started to discover that the scale challenges are very real. As a result, their IoT deployments are moving at a much slower pace than they originally hoped. In fact, many organizations are still in the POC (proof of concept) stage for IoT, even after several years of trying. Given all the hype and discussion around enterprise IoT, this is proving to be very frustrating for both end customers and the many technology companies and solution partners selling IoT-related products and services. In addition to the operational and financial challenges associated with IoT, the need for highly specialized and highly customized solutions makes IoT difficult to scale.

C. Lack of Privacy

Potentially, the Internet of Things is a wealth of information about those who use it. Smart phones can already be tracked, but smart devices point to a future where governments supplement census information with the output of smart devices, and manufacturers harvest information about your habits so efficiently that they make Facebook's insights into your interests and buying habits seem vague. You can expect the Internet of Things to produce dozens of legal precedents and class action suits as countries debate just what rights to privacy the users of smart devices retain and which they forfeit.

D. Storage Issues

Storage of information generated by smart devices will increase the energy demands required by the Internet of Things. A single corporation like Google, which already has myriad server farms, each occupying tens of thousands of square feet, could be dwarfed by the demands of smart devices. However, the physical demands are only part of the problem. Much of the data generated by smart devices is needed only briefly to send signals to device, and does not need to be stored. Other data, such as timers for devices, might ordinarily need to be stored for only a week or two at the most. Yet with such information being available, the demand may arise for storing part of this surge of information for longer periods. Consequently, policies will be needed about what kind of information is stored, and for how long -- to say nothing of who can access it, and the exceptions that might be made to whatever general policies are devised.

E. Energy Demands

Several years ago, Gartner predicted that 4.9 billion smart devices would be used by 2015 -- an increase of thirty percent from 2030. By 2020, Gartner estimated that the number of smart devices would reach 25 billion by 2020, an increase of 100% each year. Along with this boost will come an increase in energy demands comparable to the one created by the Internet. In 2012, the data centers that powered the Internet were estimated to require 30 billion watts of electricity a year - enough to power a medium-sized town, and the Internet of Things is likely to require even more. Even with improved batteries and green sources like solar and wind, just meeting the demand will be difficult. However, add issues like the wasted energy and pollutants, and powering the IoT could become a major social problem in its own right within the next decade.

F. The Need for Open Standards

The IoT consists of a lot of individual devices with their own specifications. At this stage, that hardly matters, but a time will arrive soon when further growth will require that smart devices can communicate with each other. Yet, although much of the IoT is likely to be built with open source software, universal standards and protocols lag behind the development of smart technology. The few efforts that exist tend to be specific to a technology, such as Eclipse IoT, and tend to focus on applying existing standards or protocols to smart devices rather than being developed for the new demands of the IoT. Without a greater degree of cooperation, the growth of the IoT is to be slower than it could be. [4]

V. NEED FOR INTEGRATION

IoT involves by definition a large amount of information sources. It produces a large amount of unstructured or semi-structured data of the three major characteristics of the data: volume, velocity and variety. Hence this means that the collection, acquisition, processing and visualization, archive, share, search large amounts of data. Provide almost unlimited and on-demand storage capacity, low cost, cloud is the most convenient and cost effective solutions to deal with the data generated by the Internet of things. This integration realizes a new convergence scenario, where new opportunities arise for data aggregation, integration, and sharing with third parties. Once to the cloud, data can be in a uniform way through a standard API, can use the top security protection, direct access from anywhere, and visualization. IoT equipment processing resources are not allowed to field data processing. Collected data are usually aggregated and transmitted to a more powerful node processing is feasible, but not an appropriate scalability challenges to achieve infrastructure. Cloud and its on-demand model of infinite capacity allows appropriate content, make the Internet of things to deal with unprecedented demand complex analysis. Data-driven decision making and prediction algorithms would be possible at low cost and would provide increasing revenues and reduced risks. One of the requirements of the Internet of things is to make the IP access devices communicate through dedicated hardware, and support the communication can be very expensive. Cloud connection provides an effective and cheap solution such as tracking and managing anything at any time from any place to use a custom portal and built-in applications. The integration with the Cloud solves most of these problems also providing additional features such as ease-of-access, ease-of-use, and reduced deployment costs. [5]

VI. ROLE OF CLOUD COMPUTING IN IOT

A. Remote processing power

The Internet of Things won't just stay relegated to the 'smart fridges' that first come to mind when anyone mentions this new wave of tech. On the contrary, everything will eventually be a smart device, putting new demands on raw processing power. And as miniaturization grows and 4G connectivity becomes even more widespread, the cloud will come to the rescue, allowing developers to offload processing to cloud computing services.

B. Lowers the entry bar for providers who lack infrastructure

The IT revolution has been possible only due to the constant lowering of the entry bar for innovators and developers, resulting in a world where a good idea can succeed without having the backing of a large corporation. Think back to some of the biggest names and trends in tech – the credit for so many of these goes to young, talented, creative upstarts who had a vision. The cloud will make it easier for such innovators to join the IoT revolution, offering a ready-made infrastructure into which they can just plug in their devices and services.

C. Analytics and monitoring

One of the central tenets of IoT is a more seamless experience. The cloud will help in this regard, giving device makers and service providers access to advanced analytics and monitoring. For the developer, it's a step towards constant innovation, while for the consumer, holds the promise of better reliability and a more seamless experience.

D. Smoothens inter-service and inter-device communications

The IoT isn't just about devices talking to us – it's about services and devices all talking to each other. As we've seen in the past, competing standards that work independently can often stifle product innovation and adoption. But with the Internet of things, the cloud as mediator and communication facilitator will banish these worries. Powerful APIs for app developers and product makers, cloud communications that are plug-and-play, seamless linking to our smartphones... The cloud will make this possible.

E. User security and privacy

A major concern around the mobility revolution has been the impact it has had on our privacy and security. Old devices and services often fall behind, putting consumers' data and personal privacy at risk from newly unearthed security exploits. The IoT, despite having its reach extend to every aspect of our lives, could actually sidestep this security issue, all thanks to the cloud. With devices utilizing common APIs and back-end infrastructure, vital security updates could be instantaneous and all-encompassing. [6]

VII. CHALLENGES IN INTEGRATION

We have discussed how integrating Cloud and IoT provides several benefits and fosters the birth or improvement of a number of interesting applications. At the same time, we have seen that the complex integration scenario imposes several challenges for each application that is currently receiving attention by the research community.

A. Heterogeneity.

A big challenge in the integration is related to the wide heterogeneity of devices, operating systems, platforms, and services available and possibly used for new or improved applications. Cloud platforms heterogeneity is also a non-negligible concern. Cloud services typically come with proprietary interfaces, causing resource integration and mashup to be properly customized based on the specific providers. This issue can be exacerbated when users adopt multi-cloud approaches, i.e. when services depend on multiple providers in order to improve application performance and resilience or vendor lock-in [7]. These aspects are only partially solved by cloud brokering, voluntarily implemented by cloud providers or by third parties. IoT services and applications have typically been conceived as isolated vertical solutions, in which all system components are tightly coupled to the specific application context. For each possible application/service, providers have to survey target scenarios, analyze requirements, select hardware and software environments, integrate heterogeneous subsystems, develop, provide computing infrastructure, and provide service maintenance.

B. Performance.

In particular, obtaining stable acceptable network performance to reach the Cloud is a main challenge, considering that broadband increase did not follow storage and computation evolution [8,9]. In fact, in several scenarios (e.g., when mobility is required) provisioning of data and services needs to be performed with high reactivity [10]. Since timeliness may be heavily impacted by unpredictability issues real-time applications are mainly susceptible to performance challenges [11]. Usability and user experience also can be affected by poor QoS (e.g., when multimedia streaming is needed).

C. Reliability.

When Cloud-IoT is adopted for mission-critical applications, reliability concerns typically arise e.g., in the context of smart mobility, vehicles are often on the move and the vehicular networking and communication is often intermittent or unreliable. When applications are deployed in resource constrained environments a number of challenges related to device failure or not always reachable devices exists [10]. From the one hand, Cloud capabilities help to overcome some of these challenges (e.g., Cloud enhances the reliability of the devices by allowing to offload heavy tasks and thus to increase devices' battery duration or offering the possibility of building a modularized architecture) [12]; on the other hand, it introduces uncertainties related to data center virtualization or resource exhaustion [13]. The lack of reliability analyses and of the development of specific case studies exacerbate the challenge.

D. Large Scale.

Cloud-IoT allows to design novel applications aimed at integrating and analyzing information coming from real-world (embedded) devices. Some of the depicted scenarios implicitly require the interaction with a very large number of these devices, usually distributed across wide-area environments. The large scale of the resulting systems makes typical challenges harder to overcome. Moreover, the distribution of the IoT devices makes monitoring tasks harder since they have to face latency dynamics and connectivity issues.

E. Big Data.

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 (every day 2.5 quintillion bytes of data are created) [14]. Handling this data conveniently is a critical challenge, as the overall application performance is highly dependent on the properties of the data management service [14]. Unfortunately, no perfect data management solution exists for the Cloud to manage big data.

VIII. APPLICATIONS

i. Healthcare.

The adoption of the Cloud-IoT paradigm in the healthcare field can bring several opportunities to medical IT, and experts believe that it can significantly improve healthcare services and contribute to its continuous and systematic innovation [13]. Indeed, Cloud-IoT employed in this scenario is able to simplify healthcare processes and allows to enhance the quality of the medical services by enabling the cooperation among the different entities involved. Ambient assisted living (AAL), in particular, aims at easing the daily lives of people with disabilities and chronic medical conditions. Through the application of Cloud-IoT in this field it is possible to supply many innovative services, such as: collecting patients' vital data via a network of sensors connected to medical devices, delivering the data to a medical center's Cloud for storage and processing, properly managing information provided by sensors, or guaranteeing ubiquitous access to, or sharing of, medical data as Electronic Healthcare Records (EHR) [14].

ii. Smart Home and Smart Metering.

Cloud-IoT has large application in home environments, where the joint adoption of heterogeneous embedded devices and Cloud enables the automation of common in-house activities. Indeed, the merging of computing with physical things, enables the transformation of everyday objects into information appliances which are interconnected through the Internet and can expose services through a web interface. Several smart-home applications proposed in literature involve sensor networks and realize the connection of intelligent appliances to the Internet in order to remotely monitor their behavior.

iii. Video Surveillance.

Cloud-IoT leads to easily and efficiently store, manage, and process video contents originating from video sensors and to automatically extract knowledge from scenes. It has become a tool of the greatest importance for several security-related applications. Proposed solutions are able to deliver video streams to multiple user devices through the Internet, by distributing the processing tasks over the physical server resources on-demand, in a load-balanced and fault-tolerant fashion.

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