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Internet of Things: Fundamentals and Applications

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Abstract:

The future of the Internet of Things (IoT) is unbounded. IoT allows physical devices to exchange data between each other over the network without human-to-human or human-to-computer interaction. Devices are becoming “smart” by using sensors that collect data for analysis in the cloud and/or locally, at the edge. IoT applications are already being applied in different sectors such as wearable devices, smart cities, energy management, manufacturing, and agriculture. The COVID-19 pandemic has accelerated areas of Health 4.0 (a specific part of Industry 4.0), which supports the use of IoT in the virtualization and personalization of health services. In this paper, we will look at different architectures, elements and applications of IoT systems. As the investment in IoT continues to grow, more services and applications will be implemented to benefit humans and their surrounding environment.

Table of Contents:

Introduction

Kevin Ashton - a British technology pioneer - used the term “Internet of Things” for the first time in 1999 to describe a system where objects in the physical world can be connected to the internet by sensors [1]. The revolution in mobile, internet, and machine-to-machine (M2M) connections can be thought of as the first phase of the Internet of Things (IoT). A “thing” in the IoT can be a person having a heart monitoring device, a farm animal with a biochip transponder, or an automobile with a built-in sensor [2]. IoT depends on different types of sensors embedded in devices to capture information from the physical environment. Local (or edge) processing can perform some data analysis, such as removal of unnecessary data or even some level of decision making and/or learning. The activity at the edge is almost always complemented with connections and analysis done in the cloud. Cloud computing and analysis allow for the coordination of data and activity from multiple devices while artificial intelligence (AI) and machine learning techniques allow for the interpretation of large amounts of data (Big Data) [1,2,3].

IoT provides a great investment opportunity for manufacturers, internet service providers, and application developers [3]. According to the Cisco Annual Internet Report (2018-2023), there will be 5.3 billion internet users (~66% of the global population) in 2023, increasing from 3.9 billion (~51% of the global population) in 2018. Additionally, there will be more than three times as many global population devices connected to IP networks; machine-to-machine (M2M) connections will grow from 33% in 2018 to 50% of total units in 2023

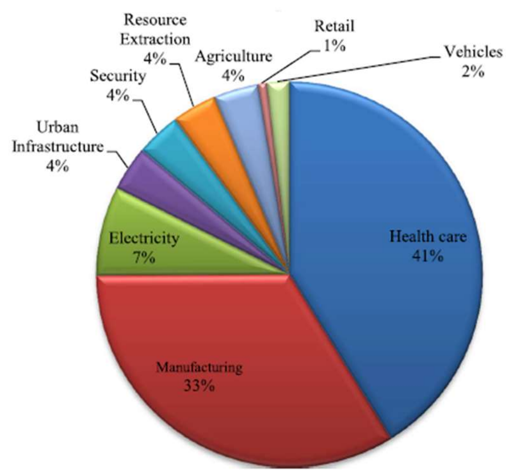

Figure 1: Economic Impact of IoT Applications by 2025

[4]. This growth will have a large impact on IoT development. Connected home applications will make up nearly half (48%) of the M2M market by 2023 while connected car applications will grow the fastest at 30% CAGR over the forecast period (2018–2023) [4]. By 2022, projections indicate that 45% of all internet traffic will consist of M2M traffic flows. By 2025, the full global economic impact of IoT is estimated to be between $2.7and $6.2 trillion [5]. Figure 1 shows the major impact of IoT on different applications. Healthcare applications including mobile health and telecare are projected to have the biggest economic impact and expected to create about $1.1–$2.5 trillion in growth annually in the global economy by 2025 [5].

With this large impact of IoT on the future economy of the world, it is important to understand the fundamentals of IoT architecture and elements.

Architecture of IoT:

Early IoT systems used basic architectures of application, network and transport/perception layers to support functionality. Due to security concerns and the advent of billions (or even trillions) of devices being connected, more robust systems became necessary. The architectural model most commonly used in IoT applications today is a 7-layer architecture shown in Figure 2.

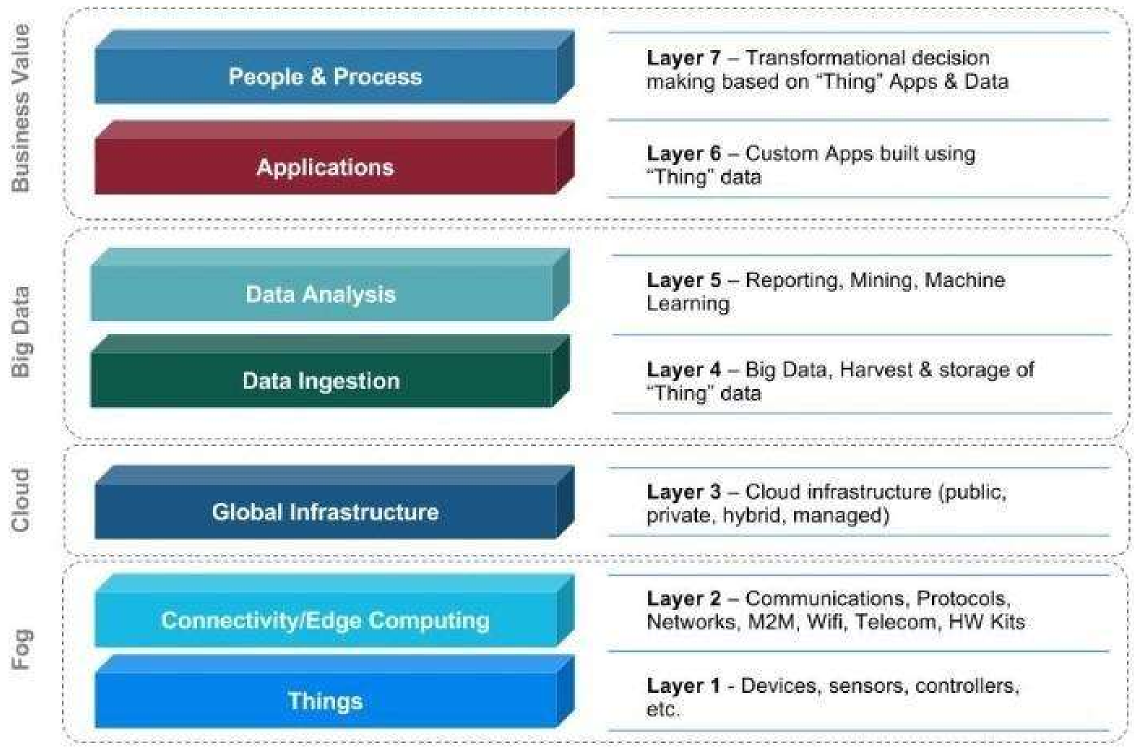

Figure 2: Seven Layers Architecture

Elements of IoT:

To support a growing variety of IoT applications and services, several elements are needed.

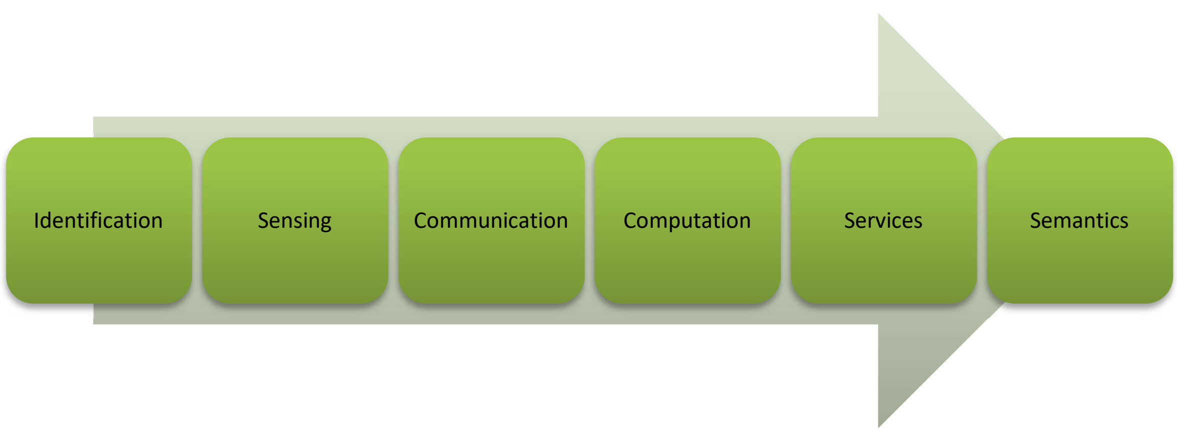

Figure 3: Six Elements of IoT

Identification:

It is crucial to correctly identify objects to match demand with the proper service [6]. Naming and addressing are the two key processes in identification. Although objects may have the same name, they will always have unique addresses [3]. There are different identification techniques available for IoT such as electronic product codes (EPC) and ubiquitous codes (uCode) [6]. The techniques used for addressing include IPv4 and the more recent expansion, IPv6 [6].

Sensing:

Sensors collect data and send it to a data warehouse, database, or the cloud. Types of IoT sensors include smart sensors, actuators, RFID tags and wearable devices [5].

Communication:

Advances in communications (particularly wireless) are one of the main reasons for the growth in IoT. Recent protocols like 5G and WiFi 6 support high throughput with fast latency and large connection density. This allows many devices to exchange a large amount of data very quickly. It also allows for IoT devices to operate at much lower power levels, helping to enable an entire new class of connected devices. Some other IoT communication protocols include Bluetooth, Z-wave, RFID, ZigBee, NFC [6].

Computation:

A combination of software and hardware components are typically involved in the sorting and processing of collected data. Some of this is done at the device itself (edge computing) using a combination of microcontrollers, microprocessors, SOCs, and FPGAs [5]. Various hardware platforms have been developed to accelerate edge computing; such as Raspberry PI and Gadgeteer [5]. Cloud computing complements activity at the edge, with the ability to handle greater amounts of data (Big Data) as well as coordinate activities among many devices.

Services:

IoT systems are providing an ever-increasing suite of services. Information aggregation and collaborative-aware applications collect data from sensors, analyze them based on defined criteria and make decisions according to a given situation. Another popular service is related to identity verification, which can be used by a host of other applications [5].

Semantics:

Semantics are the brains of IoT and refer to the ability of extracting knowledge smartly including discovery, using resources, and modeling information [5]. Advances in artificial intelligence, data analytics and machine learning have greatly increased brain power capabilities of IoT systems.

Applications of IoT:

Industry 4.0 and Smart Manufacturing

Industry 4.0, also known as the fourth industrial revolution, is regarded by many as the impending future of manufacturing. It signifies the transformation of old-fashioned industrial facilities into advanced, flexible, and automated smart facilities. IoT applications in manufacturing and factory settings are expected to generate $1.2 to $3.7 trillion of economic value annually by 2025 [7]. Smart manufacturing is enabled by IoT connected devices, big data, data analytics, robotics, machine learning, sensor technologies, and artificial intelligence. The benefits of smart manufacturing include greater operating efficiency, minimal machine downtime, increased worker safety, inventory optimization and improved supply chain management [8].

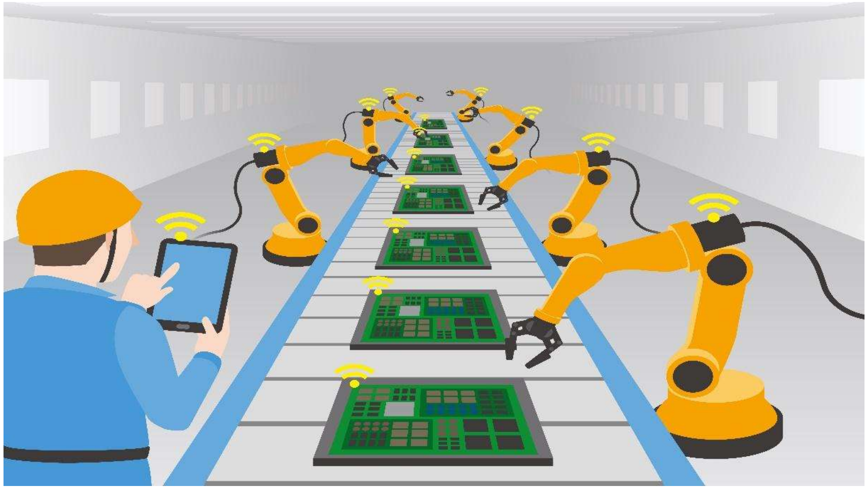

Figure 4: Smart Manufacturing

Health 4.0:

The concepts of Industry 4.0 can also be applied to the healthcare industry. Health 4.0 enables the virtualization and personalization of patient care [9]. The COVID-19 pandemic has accelerated the expansion of the role of IoT in helping to enable Health 4.0:

- *Telehealth consultation*: This makes treatment available via connected teleservices, including remote or underserved locations.
- *Wireless healthcare network to identify COVID-19 patients:* Various authentication applications can be installed into smartphones to make identification or check-in procedures smoother and less error prone.
- *Smart tracing of infected patients*: Accurate tracing of patients strengthened the ability of providers to anticipate and handle case load surges.
- *Real-time information during the spread of this infection:* Timely and accurate information can be shared to keep the public and policymakers well-informed.

- *Connecting medical tools and devices through the internet:* During COVID-19 treatment, IoT connected medical tools and devices to doctors and nurses in order to convey real-time information during treatment [10].

Wearable Devices:

The wearable devices sector is expected to reach 51.6$ billion by 2022 [11].

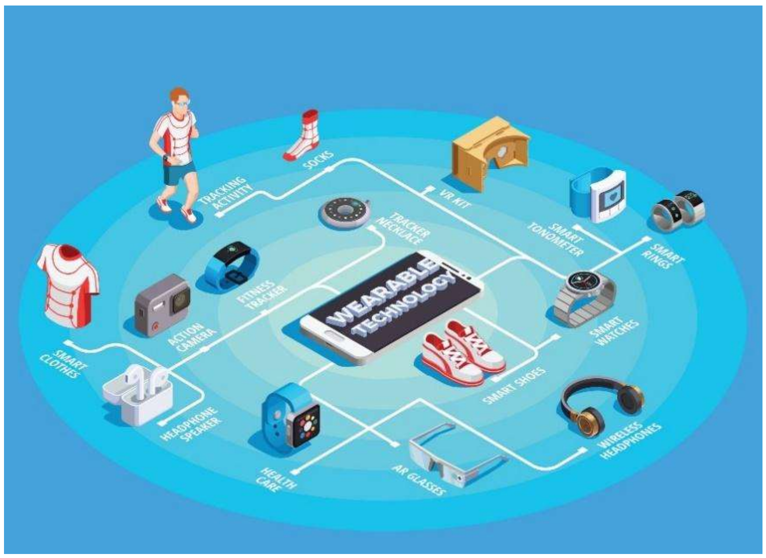

Figure 5: Some Wearable Devices

When we think about wearable devices, our thoughts go directly to smart watches or smart glasses. However, IoT and wearable technology also have great potential for so much more. One example is to help people with disabilities. The World Health Organization (WHO) estimates that 285 million people suffer from limited vision, with around 39 million people having complete blindness [11]. Toyota is developing a wearable device to assist people with vision impairment with mobility and directions. The gadget is worn on the shoulders and it uses cameras to detect and direct the user by sound and vibration [12].

Smart Cities:

54% of the global population is now living in cities, and this number is expected to increase to 66% by 2050 [13]. Implementing smart cities can help improve energy distribution, trash collection, traffic congestion, and air quality.

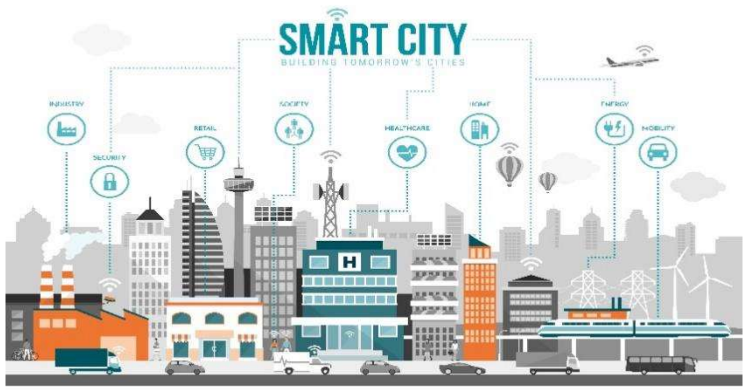

Figure 6: Smart City Concept

An example of a smart city is *Amsterdam Smart City*. The initiative of Amsterdam Smart City started in 2009 with more than 170 projects [13]. Amsterdam won Europe's Capital of Innovation award by the European Commission in April 2016 [14]. It shares traffic transportation data with developers who can create mapping applications, making city maps easily accessible to everyone [13].

Energy Management:

IoT can reduce energy spending, minimize carbon emissions, integrate green energy, automate processes, and prevent malfunctions in the grid [15]. The energy management system market is estimated to reach 9.3$ billion in 2023 [15]. These systems include sensors, actuators, meters, controls, applications, and analytics tools that enable the user to assess, control, and monitor the supply chain. Smart meters, for example, monitor power consumption in real-time, and calculate spending and share data between end-users and utility companies. This data helps suppliers tailor demand-response programs and adjust pricing. Moreover, users can control their electricity usage using applications; respond to load changes, and limit energy waste [15].

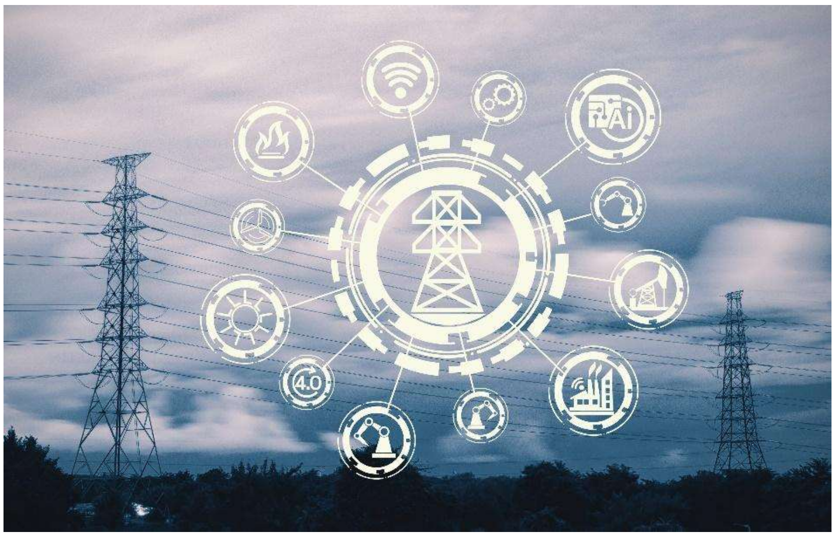

Figure7: IoT and Energy Management

Smart Agriculture:

By using IoT sensors and machine metrics, farmers can have access to data and recommendations to help improve their work from livestock to harvest. One example is the smart greenhouse. Farmers traditionally have used manual intervention to control the greenhouse environment. With an IoT enabled greenhouse, humidity, temperature, sunlight, air quality, air flow, and soil condition can be recorded, analyzed and adjusted automatically [1].

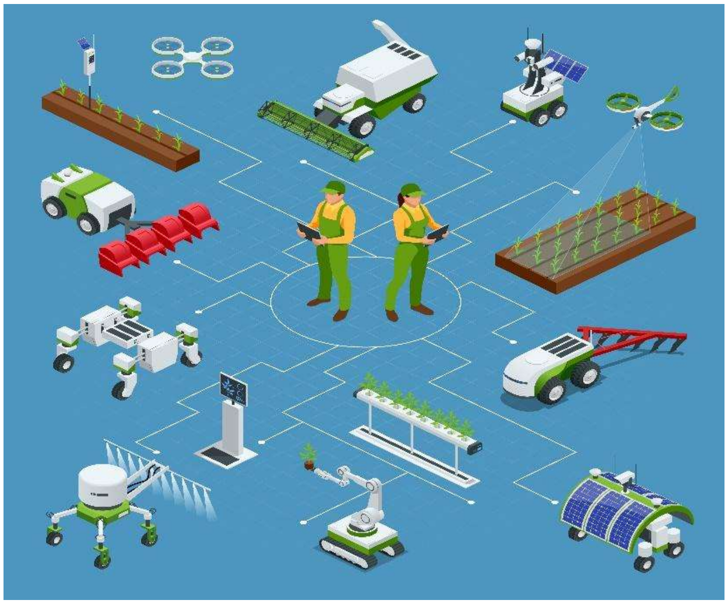

Figure 8: Smart Agriculture

Conclusion:

Internet of Things (IoT) is emerging as a key element of digital transformation. Advances in connectivity, computational power and artificial intelligence are increasing the ability of IoT to drive changes in business processes across a growing range of applications. Health care and manufacturing are initial industries leveraging the power of IoT to drive "4th generation" revolutions in personalization and flexibility. In the future, expect to see a broader range of industries and applications using IoT to shape new business models and services.

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Rayan Al Sarih is a last year Electrical and Computer Engineering Student at the American University of Beirut. She is passionate about several fields: Internet of Things, Artificial Intelligence, and Sustainable Energy. She worked with Joun Technologies on this research paper and hopes to conduct more research on related topics in the future.