Internet of Things: A Peek into the Future (December 2018)

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***Abstract*— This research paper will discuss the idea of internet of things and what it means to live in the digital age. It will follow a more traditional format as it will start of by giving a brief introduction of what it means for devices to be connected and how does one define this concept. It will then move onto how this idea begun and the first few times "Internet of Things" was constructed as an idea. Next, a quick synopsis of connectivity and transmission will be conducted. After this, it will move onto the mathematical models and the contributions of each mathematician in this field of study. Lastly, this paper will discuss applications of IoT and how this shapes our future. All of this will be followed by some challenges in scalability and how IoT compares physically to other scopes in this world.**

I. Introduction

A. General understanding of IoT

TODAY, almost everything around us is a technological device that can be connected to the internet or servers around the world. This is where the concept of Internet of Things comes into play. It can be defined as the interconnection of items that are used to sense and report real world information. IoT can also be seen as the connected sets of anyone, anything, anytime, anyplace, any service and any network. It can include various sizes of devices having various capabilities, which are all connected to the internet. This is the next technological revolution that is an approach to incorporate the internet into personal, professional and social life. This concept used to only refer to an identifiable, connected objects enabled with radio-frequency identification. Now it includes all sensors, GPD devices, mobile devices and sensors.

B. Building Blocks of IoT

To better understand this concept, it is important to include the building blocks of IoT. These include sensing, communication, computation and service. To summarize each point, IoT sensing refers to the gathering of the data from all the objects within the network. This is important as this collected data is then used to take appropriate actions for that object. For example, a power sensor for smart grid networks. IoT communication technology is the step that connects the objects together to deliver specific smart features. This connectivity is achieved through, Wi-Fi, Bluetooth, LTE, NFC (Near Field Communication). IoT computations is another building block that can be divided into processing units and cloud units. The processing unit is the operating system whereas cloud units act as the storage space for the data collected in real time IoT applications. The last block, IoT services can be divided into four classes to be fully understood. The identity related services is the foundation used in all other services. The information aggregation service collects and summarized the data. Collaborative aware services are the decision makers from the raw measurements that is obtained in the previous service. All of this is accessible through the ubiquitous services, which is the final class.

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II. Literature Review

For me to achieve the most credible information in this paper, most knowledge was retrieved from two great quality books and a journal on Internet of Things. Some of the information was also retrieved from great sources online provided by the University of Calgary. The book which is called Internet of Things, Challenges Advances and Applications is great source. It provided beautiful information on the concepts, challenges and more application by three PHD editors.

III. The Beginnings of the Internet

Arguably, the first Internet of Things (IoT) application debuted on the 22nd of November 1993 when a camera at the University of Cambridge was aimed at a coffee pot to provide several computer science researchers, located on a different floor, some indication of when the coffee would be "on" [2]. This might be a simple concept to implement. Nonetheless, it went on to show how this concept embarked human race on this journey to fully comprehend the potential of IoT.

To truly track the beginnings of this concept, it is important to share how of the internet. In 1989, the number of hosts connected to the internet was around 100,000 and only a year later the World Wide Web came to life [1]. Ten years after Tom Berners-Lee established the WWW, a whole new world of possibilities started to emerge when Kevin Ashton, from the Massachusetts Institute of Technology's (MIT) Auto-ID Labs, stamped the term Internet of Things [1]. Then In

1999, the number of hosts exceeded 2 million and the number of sites jumped to 4 million [1]. The beginnings of the twenty-first century brought an unprecedented pace of technological growth. It was clear our habits changed but more importantly our interaction with technology changed, and the way we grow, play, study, work, and communicate also changed. In 2005, the International Telecommunications Union (ITU) published its first report on the Internet of Things (IoT), noting that "Machine-to-machine communications and person-to-computer communications will be extended to things, from everyday household objects to sensors monitoring the movement of the Golden Gate Bridge or detecting earth tremors. Everything from tires to toothbrushes will fall within communications range, heralding the dawn of a new era, one in which today's internet (of data and people) gives way to tomorrow's Internet of Things." [1].

IV. Connectivity and Transmission

The foundations of IoT communication are Wi-Fi, ZigBee, Bluetooth, Radio Frequency Identification (RFID) and millimeter wave technology [2]. Due to all the different connections, it is important to establish a common protocol between communication technologies to achieve this task and reduce complexity. This is done by designing energy efficient and multi-protocol transceivers and installing them in each device [2]. This will bring about multi-channel communication among the devices. In addition, cooperative routing is another system to relay information among IoT devices [2]. This process is achieved through information being passed through intermediate devices [2]. Massive amount of smart devices in a close area will allow for better time of information transfer. All these ideas are important as it insures connection between IoT devices with the least interference and power consumption [2].

V. Mathematical Models and its History

A. *Propositional Calculus and Boolean Algebra*

Internet of Things follows a more broad study of logic [4]. The reason that propositional Calculus is discussed together with Boolean algebra is as they are closely related in this topic. The mathematics in this technology really comes down to the basics of computing. This is the same ideas that repeated in networks and the internet all of this which eventually connects all the IoT devices together. Boolean algebra is the study of mathematical logic which eventually branches out to algebra that the computer utilizes. This is also applied into circuits, as those are built out of digital logic gates [5]. These gates perform basic logic operations that can be mathematically represented by Boolean algebra. Boolean algebra is also used in simplifying these circuits [4]. All of this is important as mathematical foundations is key as all data is passed through devices with this sort of algebra. The circuits that are created by this algebra is also applied to IoT hardware.

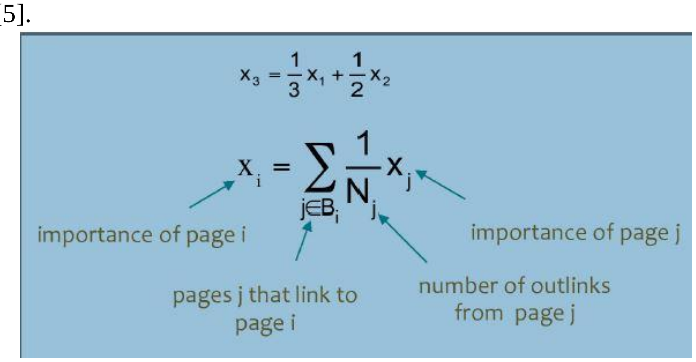
B. *Coding and Ciphering*

This is the study of representing non-numeric data [5] and is important to maintain a secure network for the all IoT devices, as there are so many. All data in a computer is represented in some form of code or cipher [5]. This Cryptography is essential for the security of wireless sensor networks [6]. There are many constraints for wireless sensor networks like processing speed, memory size and energy [6]. The encryption algorithm that is used for security must take these constraints into considerations [6]. The algorithm that is created is RC-5, which shows how plain text can be of 32,64 or 128 bits and key size can be 0 to 2048 bits [6]. There can be varying number of rounds from 0 to 255 [6]. By default it has a block size of 64-bits key size of 128 bits and 12-rounds.12-round RC-5 (with 64-bit blocks) is susceptible to a differential attack using 244 chosen plaintexts [6]. More number of rounds is suggested for better security but uses more CPU power [6]. The next algorithm that is used is Skipjack Plain text is of 64 bits and key size is 80 bits [6] . It is an unbalanced Feistel network with 32 rounds. It is prone to attacks because of its shorter length of 80 bits [6].

The given cryptographic algorithm can be used for wireless sensor networks as it uses less complex operations [6]. It is not prone to brute force attacks because of its key length (128 bits). Confusion and diffusion is also achieved through this algorithm [6]. Hence even a single bit change in the plain text or master key changes the cipher text completely. Similarly the integrity algorithm can also be used for ultra-low power devices [6].

C. *Linear Algebra and Vectors*

The links of the things that connect each other over the internet move on to further connections with other devices and all of this eventually gives a system of equations [5]. This logic is seen through webpages and applied to things that are connected to the internet as well. When the system of equations are set up in way they can be solved, in the case below, it explains the set up on each item or link. The importance of a link connected is given by the weighted importance of all the pages, which is multiplied 1 over the out links, that one refreshes to. This is done added in a matrix so that coefficient can be added and then equal to the total number of pages [5]. The 0 coefficient would represent if that link does not link. The P represents the probability matrix, which represents the probability one would click on the link [5].



Referenced from [5].

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 1/3 & 0 & 0 & 0 & 0 & 0 \\ 1/3 & 1/2 & 0 & 0 & 0 & 0 \\ 1/3 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1/2 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix}$$

$$\mathbf{x = Px}$$

Referenced from [5].

This can be seen that the vector space is really important in the applications of internet and how these algorithms come to be the way they are.

	B1	B2	B3	B4	...	B7	B8	...	B11	...	B17
algorithms	0	0	1	0	...	1	0	...	0	...	0
application	0	0	1	0	...	0	0	...	0	...	1
delay	0	0	0	0	...	0	0	...	1	...	0
differential	0	0	0	1	...	0	1	...	1	...	0
:	:	:	:	:		:	:		:		:
systems	0	0	0	0	...	0	1	...	0	...	0
theory	0	0	1	0	...	0	0	...	1	...	1

Referenced from [5].

D. *History of These ideas*

The mathematicians that will be discusses who have contributed significantly to the important aspects behind computers. These people are primarily those who have contributed to the theoretical underpinnings of computing, rather than the implementation of hardware or software [5]. Leon Battista Alberti from the 1400's made a scientific study of perspective visualization. His mathematical interpretation of 3D objects as 2D images is the foundation of computer graphics [5]. Gottfried Leibnitz (1600's) described the binary number system [5]. Blaise Pascal (1600's): developed the first mechanical calculator. Charles Babbage and Ada Lovelace (1800's): invented the first mechanical computer with stored program capabilities, and wrote the first algorithmic computer program [5]. George Boole (1800's), developed an algebraic system for logic, which is today known as boolean algebra [5]. Herman Goldstone (1940's) invented the flowchart. John W. Mauchly and William F. Schmitt (1940's) developed Short Code, the first "high-level" programming language [5]. Dr. Alan Turing (1950's) developed a "Turing Test" for determining machine intelligence. He is also famous for his contribution in WWII. Diffie-Hellman-Merkle (1970's), developed a key exchange algorithm (foundations of public key encryption.). Fiat Shamir (1980's), developed zero-knowledge-based data encryption [5].

VI. Applications of IoT and the Future

As more devices are connecting to the internet, the applications of IoT has a wide range of implementation into our daily lives. These are a few applications that are useful and some that greatly eases our life in the future:

A. *Intelligent Transportation*

It is possible to apply the principles of IoT to vehicles which allows nearby cars to exchange high rate multimedia information for entertainment purposes [1]. These networks are called Vehicular Ad-Hoc Networks (VANET). In addition, device-to-device communication is another building block of IoT where the promising applications of network control over communication sessions, whereby the devices discover each other and directly communicate with minimal involvement of the network [2]. This strategy can help overcome latency issues in scenarios where vehicles communicate directly with each other, i.e., vehicle-to-vehicle [2]. Though there are still some constraints as the connection will be lost if the range exceeds 100-300 meters [2]. There still needs to be done more work on this area as the range needs to increase to make this application more useful.

B. *Smart Clothes*

The current state of smart clothing is restricted to special purpose, low-volume fabrics that have electronic systems embedded in them [2]. However there can be projection where these garments can reach a level of production that the IoT device can be incorporated in the sensing layers, such as the coating or the mesh of the thread [2]. However, this can be complicated as there are a few requirements to reach this. First being where to include the sensor layer as it has to be incorporated in a way so it provides the appropriate function to the correct part of the body [2]. Then the connectivity between the sensor layers needs to be achieved that the infrastructure is powerful. Finally, the interface has to be embedded in the so the electronic circuitry doesn't interfere with the comfort of the clothes.

C. *Education*

This major incorporation of IoT to Global education can be done in a way so there is a major boost with the introduction of massive open online courses (MOOCs) [2]. With the world's leading universities providing access to their professors free of charge, the idea of "flipped classrooms" is gaining strength, whereby students would be expected to learn their subjects outside the classroom, leaving the course instructor to discuss problems and ideas during class time [2]. By providing an opportunity for students in the developing world to learn beyond basic education (which is often limited by the economic status), MOOCs and other online resources like Khan Academy can, in time, help improve the quality of life for people who cannot afford higher education [2]. This is beneficial as education can be vastly available to people all around. Another benefit of this application would be individuals who are home-bound but are capable of learning and participate in classroom courses [2].

Another great application can be seen in the future when, this massive open online courses may transform into an area where there is information received to the university about who is engaged in furthering their knowledge and who is not [2]. This can generate sets outlining the number of registrations and drop-outs, online attendance per course and the students' internet protocol (IP) address of the students [2]. This will be useful as universities can spend time to further realize course materials and narrow down the content and topics that might be popular [2].

D. Environment Protection

In today's day and age, the environment is under constant stress due to extensive urbanization and human activities such as hunting for sport and exceeding fishing [2]. This is where IoT is projected to play a part in preserving natural resources and endangered species. In order to achieve the latter objective, organizations around the world are using GPS-enabled devices to track the habits and health of endangered species [2]. This is beneficial as specific actions can be taken from this data which is observed.

Furthermore, IoT can potentially help alleviate waste management issues particularly in countries like the USA where the daily per capita trash was estimated to be 4.6 pounds in 2013 [2]. This can be done through the optimum time for waste collection and the best routes for the trucks to follow, IoT can redress the problems associated with waste build-up in neighborhoods [2].With an increasing number of water-stressed countries around the world, the installation of smart water sensors in buildings can also help limit domestic water consumption [2]. Through these devices and data analytics, users will be able to keep track of how much water was used in during a specific time, allowing them to cut down on excessive usage [2].

Another major environmental dilemma that we currently face is deforestation. In addition to fighting forest fires, drones are now part of an initiative by BioCarbon Engineering to replant one billion trees [2]. The organization aims to achieve its goals through precision agriculture techniques, the use of technology to reduce manpower requirements and cost and the deployment of drones to determine the landscape of the area affected by deforestation [2].

E. Agriculture

Sensors and actuators play an essential role to better the current state of farming. There is a 60% loss of water due to faulty irrigation systems [2]. Sensors and Actuators start by providing farmers with a better visibility over their operation and thus allow them to minimize water wastage by monitoring metrics such as temperature and water pressure [2]. There is a great company Microstrain that has developed a system of wireless sensors to insert conditions which the gauge releases water or other liquids during the growing season in vineyards [2]. The sensors measure variables such as temperature, soil moisture and solar radiation and alert the farmers when extreme conditions are evident [2].

F. Health Care

To begin, IoT can help physicians to monitor the physiological parameters of their patients at all times [2]. The recent advances in wireless sensor networks and embedded systems, miniature health monitoring devices are possible [2].

In addition, sensors can form a body sensor network (BSN) which not only monitors the patients' health indicators but also incorporates context aware sensing for improved sensitivity [2]. The diagnosis of cardiac diseases by constantly monitoring the patient's electrocardiogram (ECG) signals is a common application of BSNs. These sensor network shave also been used for monitoring patients with Parkinson's disease as they offer credible data collected over a larger period of time, compared to the inferences made through clinical observation [2]. For example, authors used wearable sensors to identify the movement characteristics of patients suffering from Parkinson's disease and attained real-time monitoring with high accuracy [2].

G. Smart Grids

In today's smart items, smart meters are restricted to measuring the electricity used and the ability to remotely control the supply and cutoff when necessary. However, this application can be further advanced when incorporating IoT principles into future electric grids. This would mean that smart meters will be able to perform a more diverse set of operations in the smart grid [2]. These include, new features like real-time determination of electricity consumption with the possibility of remote and local reading of the meter, linkage with other utilities such as gas and water supply and recording events such as device status and power quality [2].

VII. Scalability for IoT

Everyday more devices are connecting to the internet, so large that by 2020 over fifty billion smart things or objects are going to be connected [3]. This is important to consider as it will impact the future application domains needs to have its own addresses. Though we were able to credit Internet Protocol 6 (IPv6) for network protocol and replacing IPv4, it comes with many of its own challenges.

It is still unbelievable for me to comprehend IPv6 has 128 bits addresses which allows 3x10^38 unique IP addresses [3]. However, one must consider that not all addresses are usable are some are blocked due to IPv4 allocations. Therefore, at least two levels of scalability must be considered, network and data scalability. The network growth is hard to maintain as IoT must guarantee interoperability as well as data security and privacy [1]. This is really difficult as energy consumption also becomes an issue and safety between all the computer systems exchanging information. It also adds on to more problems as so many different types of devices generating data, there are many reasons why this data may be stored in disparate data storage: there might be too much data to put in one place; transferring data into a database might consume too much processing power, so it is recommended that data is retrieved separately from the data generation process [1]. This leads to how different kinds of data processing might be required [1].

This is beautifully incorporation to show someone how large this number is with this scale below. Personally, I have always tried to imagine these numbers when I thought of space but it is still unfathomable that those IP addresses are larger than stars or atoms in our body. It really goes on to show how technology can be compared to such a large scale. Referenced from [3].

~4,3 x 10^{9}	IPv4 addresses (2^{32})
~7,3 x 10^{9}	Human beings on earth [20]
~5 x 10^{10}	IoT devices by 2020 [21]
~1 x 10^{11}	Planets in our galaxy
~8,6 x 10^{11}	Neurons in a brain [22]
~2 x 10^{12}	Galaxies in the universe [23]
~5,1 x 10^{14}	Square meters on the Earth surface [24]
~1 x 10^{15}	Synapses in a brain [25]
~7,5 x 10^{18}	Grains of sand on earth [26]
~5,1 x 10^{20}	Square millimetres on the Earth [24]
~3 x 10^{23}	Stars in the universe [27]

~7 x 10^{27}	Atoms in one human body [28]
~5,1 x 10^{37}	Atoms in all human bodies (from the above)
~3,4 x 10^{38}	IPv6 addresses (2^{128})

VIII. Conclusion

To conclude, Internet of Things is comparatively a new topic that is established in today's ark of technology. Though it has some great mathematical models and the applications of this is evident in many different fields, there is still much more to learn. Every time, we are able to see a new way to solve a problem through the connection of these of objects, it brings along many challenges with it. The building blocks of IoT can soon grow and not only include sensing, communication, computation and service. The first application at the University of Cambridge can grow to become revolutionary as it can bring along a new era of for human kind. The simple mathematics of Boolean algebra and discrete mathematics can grow to apply more new ideas in this topic. It might also be able to apply in topics that are move further than education, health care and

Acknowledgment

Hamza Farhat thanks the very knowledgeable people at the University of Calgary, University of Guelp and last but not least the professors and T.A.s of UOIT to help students achieve their goals. "

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