IoT: Systematic Review, Architecture, Applications and Dual Impact on Industries

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Abstract. The role of IoT in every aspect of human life is capacious. IoT being immensely popular technology, offers every possible solution to modernize life. Due to the omnipresence of internet, IoT offers substantial growth in almost all industrial domains. IoT is expected to make a remarkable difference in the revenue generated by various sectors, by combining it with other latest technologies. But this may also lead to unforeseen risks and challenges. A systematic review has been done, by conducting a survey of the detailed impact of IoT on various industrial domains. The research also explores a novel approach to integrate various technologies like fog and cloud with IoT. Various challenges encountered in the growth of IoT have also been analyzed, including security challenges and different methods to elucidate the issues have also been studied. Moreover, a standard generalized architecture of IoT technology has been presented which encompasses all the application domains. Lastly, different kinds of open issues and challenges have been discussed so that the researchers can work efficiently in future in various domains of IoT.

Keywords: Internet of Things; Internet of Everything IoE; fog computing; cloud computing

1. Introduction

The IoT or the ‘Future Internet’ as it is referred to, includes enormous interconnected devices also known as ‘smart objects’ encompassing a world-wide network with anytime and everywhere availability. Internet of Things may be defined as the network of physical “objects” containing embedded technology so that devices can communicate and interact with each other and the external environment [1]. IoT is basically the infusion of ‘Things’ like RFID tags, actuators, sensors, mobile phones using IPV6 addressing technique for communication [2]. IoT which marks the third wave of information technology revolution after mobile communication and internet has changed our lives like never before.

Although the term IoT was coined in 1999 by Kevin Ashton, while working with a network of RFID objects at Proctor & Gamble but the first publication having the term IoT was in 2005, by ITU-T in a RFID journal [3]. The introduction of smart phones in 2005 helped the concept of IoT gain momentum. However, after 2008, the number of devices connected by IoT exceeded the number of people which lead IoT to be called as IoE (Internet of Everything) [4]. IoT market is expected to generate a huge volume of profit which will exceed the combined profit of phones and PC market combined, with smart homes being the largest contributors generating a net profit of $500 billion. The advancement in networking technologies has lead billions of devices across the world to interconnect [5]. In 5G enabled industrial automation environment, high speed device-to-device(D2D) interactions and plug-in communication between machines, data and humans is made possible only with the help of IoT. As per an estimate by Cisco, the number of IoT operational devices would be somewhere about 24 billion devices by the end of this year and will reach 11 trillion devices every year by 2025 [6]. IoE (Internet of Everything) which is the superset containing IoT and having coordination between...
three prime elements: people, process and data includes different technologies and variable platforms for analyzing data.

The objects or ‘Things’ in the IoT network are connected by using unique RFID (Radio Frequency Identification) tags and various kinds of sensors. However, the heterogeneity of objects poses another serious challenge. The working of IoT involves amalgamation of various technologies like sensor technology, Nano- technology, RFID technology and smart technology, predictive analysis, artificial intelligence and many more [2, 7]. The various elements of IoT are depicted in Fig 1.

**Fig 1. Components of IoT**

The concept of IoT no matter how life changing it may sound, has some really serious issues to address, which restrict its full functionality in one way or other. Some of them are interoperability among interconnected devices, achieving higher degree of intelligence and independence by devices, maintaining trust, security and privacy which will be discussed in details later.

### 2. Motivation & Contribution

The motivation for making an exhaustive survey emerges from the fact that IoT being an impeccable technology has paramount influence on every aspect of our life. We can derive maximum benefits out of this technology only if we have an in-depth knowledge of the concept, its potential in various industries and its challenges and we make an effort to develop a generalized architecture. Hence for IoT to diversify the course of technological advancements, there is much need for focus and dedication in this direction.

IoT is going to revolutionize the world economy in the coming years. About $6 trillion of capital is expected to be spent on this technology in the coming years. According to a report by Cisco Internet Business Group, for every person there will be more than 7 devices connected to internet in the coming years [8]. In future, IoT is going to make the automation of everything around us possible. Thus, the impact of IoT on every industry is going to be remarkable on every industry.

### 3. Background and Future growth
The evolution of IoT has started as long as two decades ago with the introduction of various technologies [9]. The significant technologies responsible for the evolution of IoT have been summarized in table 1. The Technologies which lead to the development of IoT in chronological order can be enlisted as:

3.1 *Internet*: The backbone technology behind IoT was Internet which was developed by Advanced Research Project Agency Network (ARPANET) in 1969. At that time, it was only in use by defense, research and academic fraternity in United States [10].

3.2 *RFID*: This was another foundation stone for IoT, developed in 1974. It was in year 1973, that the first patent for RFID (Radio Frequency Identification) tag was received by Mario W. Cardullo.

3.3 *Embedded systems*: The embedded computer system, implemented by using microcontrollers with single board computers came into being in the year 1974.

3.4 *Beginning of IoT*: In 1984 an internet connection was established on a coke machine to indentify temperature and availability of the drink.

3.5 *Ubiquitous Computing and Sensors*: The Idea of Pervasive Computing was proposed by Mark Weiser in 1991. It involved use of advanced embedded computing, reducing the computer size to almost negligible. It was during this time that various types of sensors also came into existence.

3.6 *IoT*: It was in year 1999, that Kevin Ashton used the term IoT for the first time and Bill Joy introduced the concept of Device to Device communication. Moreover, a lab was also established at Massachusetts Institute of Technology (MIT) to work in the area of establishing internet connections among objects.

3.7 *Boon of Digitalization*: From 2000 onwards, Internet became the necessity of almost all applications, and various business solutions also turned totally dependent on internet. This also increased the popularity and focus of research on IoT.

3.8 *Use of IoT in vertical market applications*: It was in year 2010, that IoT came to be used in various generalized domains like surveillance, health care, security, transport and food safety due to cost reduction and better connectivity.

3.9 *Ubiquitous Positioning*: By 2015, geological positioning of people and everyday objects became possible.

3.10 *Physical World Web*: By 2020, Tele operations and Tele presence i.e.; the ability to control and monitor distant objects over the internet became possible. The miniaturization and power efficiency of electronic objects was also improved considerably.
According to Kurzweil curve in “The Law of Accelerating Returns”, there would be an exponential increase in intelligence of devices and the intelligence engulfed by computing platforms will be similar to that of human brain, by the end of decade [11]. This increase would be a result of exponentially generated data from IoT devices, advanced AI algorithms and low power requirements. As per the reports from IDC, considering the market size IoT investment is expected to increase 15.4% year to year growth and the global market revenue will reach US$1.1 trillion by 2025[5].

### 4. Methodologies and Architecture

Since IoT is used to connect billions of smart objects, there is a great need for a standard flexible architecture. Various authors have made an effort in this context, but every architecture lacks in one way or the other [13,9,10,14]. Nowadays, majority of IoT-based systems are built by using three important pillars i.e.; strong database, centralized client-server and cloud servers, [15,16] with the Internet. However, this leads to two major limitations; (i) the single point failure, which can potentially mess with the entire system and (ii) trust issues between the entities involved in the system [17]. To overcome the enlisted limitations, the approach of decentralized architectures can be used for peer-to-peer (P2P) communications among the nodes.

After studying the architectures designed by various researchers, and observing the shortcomings in them, we have also made an effort to provide a standard architecture which can be used by all applications. As shown in Fig 2, It consists of five layers which can be described

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**Table 1: Evolution of IoT**

| Year | Development   | Description                                                                 |
|------|---------------|-----------------------------------------------------------------------------|
| 1969 | Internet      | Internet used by ARPANET                                                    |
| 1973 | RFID          | Patented by Mario Cardullo                                                  |
| 1974 | Embedded Systems | Single board computers & microcontrollers                                  |
| 1984 | Beginning of IoT | Internet used by a coke machine to identify temperature and availability |
| 1991 | Ubiquitous Computing | Pervasive Computing introduced by Mark Weiser                            |
| 1999 | Using Term IoT     | Lab developed at MIT, USA                                                   |
| 2000 | Internet Based Applications | Wide use of sensors                                                     |
| 2010 | Smart Health Care, Food Safety Security | New applications due to cost reduction and better connectivity |
| 2015 | Ubiquitous Positioning | Geographical positioning of objects                                       |
| 2020 | Physical World Web | Tele operations and Tele Presence                                          |
as:

4.1 Hardware and Coding Layer: This layer consists of all the hardware required for connectivity like sensors, RFID tags, actuators which are used to collect and process information in an IoT ecosystem. The sensors used operate on plug-and-play principle and are of various types like thermal, pressure, weight, motion, humidity, location etc depending on the functionality required. This layer is responsible for analyzing this data and using secure channels for transferring this digitalized data to the upper layers for modification. The biggest challenge at this layer is the presence of heterogeneous devices and more utilization of energy.

4.2 Abstraction and Coordination Layer: This layer constitutes a universal virtual network and makes use of technologies like Zigbee, 4G/LTE, WIFI, Wave, GSM for transferring the data securely to upper layers for further processing. The pooling of data by using cloud or fog computing is also done at this layer. This layer is also responsible for proving network support and re organizing data received from heterogeneous devices and converting it into unified formats for processing by other upper layers. The most important challenge of this layer is issue in coordination of different networks due to lack of standards.

4.3 Network and Service Management Layer: This layer makes use of IPV6 addressing scheme to assign addresses to various objects transferring data in the IoT network and pairing services with the requester device based on its IP address. This layer also makes use of various protocols like, CoAP, DDS, MQTT, AMQP, XMPP. This layer makes use of two important technologies: virtual cloud for storing information, Big Data Analysis for identifying critical data and Machine Learning for intelligent decision making. This layer is very important from IoT framework point of view and offers many services.

4.4 Application Layer: This layer is responsible for providing smart services to end users like health monitoring information or geographical details. This is the layer dealing with customer demands and needs. This layer covers numerous vertical market applications of IoT like smart homes, smart healthcare, smart industries and smart vehicles. This layer holds great significance as it holds a plethora of applications leading to expansion of IoT market. Privacy and security are the major concerns of this layer.

4.5 Business Layer: This is the top layer of IoT architecture and is responsible for management of services provided by Application layer. This layer is also responsible for figuring out strategies for developing various business models based on analyzing the data statistically and developing economic investment decisions and budgets. Comparison of output expected with the output achieved is also done at this layer by using Big Data techniques. Various tools used by this layer for analysis include flowcharts, graphs, pie charts, comparison tables and so on.
Fig 2: Architectural Framework of IoT

5. IoT and Other Technologies
In collaboration with eminent technologies, IoT has a great potential in providing the epitome of services for human comfort. The integration and working of IoT with such technologies has been illustrated in Fig 3.

5.1 IoT and Cloud: The combination of vast storage and pooling of available resources from cloud and on-demand and smart services from IoT provides a lot of advantages. Using cloud computing, IoT services, applications and resources can be managed very efficiently. Cloud also offers an efficient storage for the vast amount of data generated by IoT devices. Hence, standardization of available protocols and interfaces is the need of the hour. Cloud makes the scalability realistic by providing data management in both smart devices and end users. Cloud also addresses the issues of huge power and battery consumption by providing data transmission and communication with increased speed and by providing caching and data compression. Cloud also curbs security and privacy threats to some extent by using restrictive policies, providing access only to legitimate users [18-21].

5.2 IoT and Big Data: IoT is one of the leading contributors of Big Data due to enormous amount of data being generated every now and then. Due to the total number of sensors connected to the IoT network increasing, it is estimated that the deployment of sensors will cross trillions by the year 2030. The Big Data techniques are quite beneficial in handling data collected by IoT Sensors. The data collected is heterogeneous and requires preprocessing before analysis [13]. Data collected also requires cleaning and identification by using Big Data analysis and identification of important data from it so as to save time and effort. For instance, while dealing with data from a smart health monitoring system of a patient, only the data showing variations in health conditions is important as compared to the data pattern showing the patient healthy [22-25].
5.3 IoT and Block chain: This serves as an important technology for maintaining the security and response time of IoT devices. There are various Block chain solutions available which can be used both in trusted and unreliable networks. Blockchain makes use of strong encryption algorithms to provide high security to IoT network. Use of Block chain in a decentralized paradigm helps to eliminate ‘man-in-the-middle’ attack. The integration of Blockchain and IoT will have remarkable outcomes in industrial automation [26].

5.4 IoT and Machine Learning: As the volume of data is increasing exponentially, the extraction of relevant information from this data becomes difficult. Thus, various machine learning algorithms come to the rescue to extract higher level information from such data. Machine Learning makes the devices smarter by getting an insight into human behavioral patterns. Machine Learning method are also of great use in transforming the security of IoT systems using Intelligent systems [27].

5.5 LoRa and NB-IoT: There is a great demand for LPWA (low power wide area) technologies, with rapid growth in IoT. Two leading technologies in this context are LoRa (Long Range) and NB (narrowband)IoT. LoRa being unlicensed has great advantages in terms of battery life, cost and capacity whereas NB-IoT being licensed has advantages in terms of latency, range, QoS and reliability. LoRa is suitable for applications which need to transmit tiny amounts of information over a long range whereas NB-IoT is better in situations which need to transfer critical data. With the emergence of both the LPWA technologies in 2013, power issues while communication among the nodes in IoT ecosystem has improved considerably [28].
6. Dual Impact of IoT in Industries

IoT has the potential of bringing one of the biggest economic revolutions. The market for IoT is expanding with every passing day as many technology giants are investing in it. Companies like Google, Samsung, IBM are into development of technologies related to IoT. However, the impact of IoT does not only have a brighter side. There are also several risks related to the same. The following points helps us to get a clear idea about the dual nature of IoT [29]

1. The privacy of an individual can be invaded by data leaks, by revealing all the sensitive information related to personal and financial conditions.

2. There can be unauthorized access and misuse of information which becomes difficult owing to the velocity and veracity of Big Data generated.

3. Due to automation of everything in the coming years, there would be changes in staff and organizational structure in the coming years which is not great from social point of view.

Despite all the concerns in application of IoT, there is still a lot of scope for revenue generation and improving the life standards of people to a great extent. The applications of IoT can be grouped into two categories as shown in Fig 4 [26,13, 10,30,31]

Fig 4: Categorization of IoT application Domains

6.1 User Oriented Applications: This category includes the applications of IoT which directly have an impact over the user or customer. These include:

6.1.1 Smart Healthcare: Also known as Healthcare 4.0, offers remote health monitoring by using IoT sensors to analyze and measure different health conditions. Patient health records are then collected digitally by using Electronic Health Records (EHR), handling the private information sensitively. Such systems are of great help to diabetic patients and others who require constant monitoring and supervision from specialized doctors. IoT healthcare has a huge role to play in the times of COVID pandemic, where the patients are in bulk and the disease is highly contagious. The doctors can assist the patients by providing online guidelines and prescriptions.
6.1.2 Smart Homes: A smart home may be referred to as a highly technological living environment. A smart Home consists of comfort, security, convenience by letting the inhabitant’s control and automate all the setting as per their preferences by using Smart Phone applications. A Smart Home consists of IoT-enabled sensors, uninterrupted internet and Smart phone for remote access. Some services provided by smart homes are smart parking, smart door lock, smart lighting, smart thermostat, video surveillance.

6.1.3 Smart Agriculture: In Smart agriculture modern technologies, like IoT, Big Data and GPS are used to improve the quality and quantity of agricultural products. Various metrics affecting the output like light, humidity, moisture, temperature is stored in a data pool and then this information is analyzed to take actions by using Machine Learning Algorithms. Using such advance agricultural practices enhances the product quality and quantity by many folds.

6.1.4 Smart Vehicles: IoT has led to development of Intelligent Transportation System (IT) which makes the vehicles smarter and safer. The transportation systems developed using this approach need to be resilient to various malicious data attacks. IoT has also led to development of Parallel Transportation Management system, in which vehicles support parallel interactions with their counterparts and support ride sharing options with proper security measures in mind. Various Cab Sharing options like Uber are a perfect example of this, and IoT focuses to make them more secure and better.

6.2 Industry Oriented Applications: These are the applications of IoT which target large industries and have a direct impact on industrial growth and revenue while as an indirect impact on customer. The concept of industrial automation in production also known as Industry 4.0, brings massive technological developments. The economic impact caused by IoT in Industrial sectors is impressive, this becomes evident from the data shown in Fig 5. Various applications in this area are:

6.2.1 Manufacturing Sector: IoT is changing the face of manufacturing industry by using automation. This sector contributes about 34 percent of IoT generated profit. With IoT, this sector will contribute to almost $141 million revenue yearly which is much more than what it is today [32]. The effect of IoT in manufacturing will give rise to faster manufacturing of goods, improved quality, low cost and efficiency and remote management in real time. According to a SCM World’s survey nearly one out of every five factories gets all of its work done offline, which will drop to zero in the coming future. Based on the use of IoT in manufacturing, manufacturers fall into three categories: - early adopters (who are already using IoT technology), sideliners (who are doing a little using IoT) and Waders (those who are thinking of adopting the technology). Various manufacturing industries like Cisco, GE, Harley-Davidson, and Siemens have already moving towards Smart manufacturing. The use of IoT in manufacturing serves various purposes. It ensures the safety of the workers. e.g.; in a company named Sine-Wave, a business solution company the IoT has been used to create a program for ensuring safety in mines. They have designed a browser-based app which helps the workers to communicate in the mine with users, operators, machines and get a real time view of all the activities involved in mining operation. Thus, if any undesirable thing happens, it can be easily communicated and respective actions can be taken [33].

6.2.2 Retail Industry: Almost 79 percent of the retail industries would be switching to complete IoT solutions in the coming years according to a research by Cisco. This sector would contribute to almost $20 billion revenue annually. IoT in industry improves both customers and retailers experience. It will greatly enhance the availability in retail industry by improving the
stock of items, better sale options, predictive arrangement and demand of commodities, detection of risk and hence preventing loss and so on. On customers end, things like finding out location of products, payments for them, checking their quality are done easily by using various tools like Qminder and Waitbot[32]. IoT in retail industry has led the retailers use a new concept of “Hyper-relevance”, which means to give output up to full potential, the retailer must completely understand the shopping behavior of customers, and must be able to take correct actions by using Deep Learning Algorithms.

Fig 5: Economic impact of IoT on various Industrial Sectors

6.2.3 Supply Chain Management: SCM is the process of managing information, materials and finances as products move through a process in the supply chain. Using IoT we can increase the bandwidth capacity for transmission of goods-related data securely. Moreover, it also favors the secure storage of data. Use of IoT and Block Chain in collaboration can enable automatic payment of goods upon their receipt, thereby eliminate the need for a third-party confirmation. IoT also enables use of Smart Contracts to track shipments and provide coordination among different agents of the system.

6.2.4 Urban Infrastructure: This Sector will contribute to about 20 percent of profit generated from IoT. The impact on this sector would mostly be seen in cities [22]. Somewhere around 86 percent industries in this sector would be IoT based in the next three years, according to a report by Cisco [11]. IoT aims at improving employee productivity, reduce cost, and utilize public resources efficiently. In a report, Cisco highlighted major areas which would be mainly affected by IoT in public sector which includes: -Smart Parking systems, Smart resource managing systems mainly water and gas, Smart healthcare systems, Smart military systems and
Smart learning. The development of these Smart environments would result in great economic savings.

7. Challenges

7.1. Interoperability: This problem has been around since a long time. Interoperability means the devices being able to communicate, operate and exchange information with each other i.e.; understanding and supporting each other’s functionality. Interoperability issue arises in IoT by lack of standardization. There have been several efforts to agree on common standards but none has been successful so far. The diversity of several interoperability challenges effects IoT immensely. These challenges are highlighted in Fig 6. Addressing this challenge is so important that according to researchers 40% of benefits can be obtained by achieving interoperability between devices [2]. Interoperability issue also arises from integration of various other technologies like fog computing with IoT [16].

Lack of interoperability also leads to increased operational cost in IoT by investing in heterogeneous devices and interfaces. The issue of interoperability can be better addressed by having a detailed idea of different types of interoperability prevalent in IoT domain [2]

7.2. Security and Privacy: Security and privacy are among the major concerns regarding the development of IoT. For IoT to become a success, it is mandatory to address these issues. Some of the major security and privacy issues encountered by IoT applications are enlisted below [13]:

7.2.1 Entry of Malicious Data: IoT encompasses a he networks of nodes, and a possibility of adding even a single malicious node to the network will lead to the whole system being infected.

7.2.2 Denial of Service Attack: DoS is among the most vicious attacks over a IoT network.
Unavailability of services and misuse of network resources can prove fatal in case of IoT. One of the unique type Botnet namely ‘Mirai’ has caused various large-scale DDoS attacks exploiting a huge number of IoT devices [27].

7.2.3 *Replay Attack:* This attack leads to adversary replays a previous message to the destination node so as to compromise the network trust and authentication schemes.

7.2.4 *Lack of authentication:* Due to large number of devices, entering and leaving the network continuously, there is lack of authentication and depletion of network resources.

7.2.5 *Misuse of Information:* Due to large number of devices, a large number of data is also collected. This data can be accessed by any unauthentic person and misused.

7.2.6 *Lack of Privacy:* There is no privacy regarding the data shared by users.

7.3 *Reliability:* Reliability means proper delivery and working on system as per its specifications. It is very important to have proper reliability throughout all the layers of the IoT both in terms of hardware and software. Communication between the devices should be reliable to avoid delays, loss of data. It can be challenging to achieve reliability while dealing with massive amount of data and dependencies due to various technologies like cloud and IoT operating together. Various probabilistic models have been used to develop methods to keep check on reliability [10].

7.4 *Performance:* Performance evaluation is also an important metric to be achieved and measured in an IoT environment. The overall performance can be achieved by improving the performance of individual components. All the IoT devices need to be continuously monitored to give the best performance. Main factors having an impact on the performance include: device form factor, cost and communication speed [10].

7.5 *Prevention:* The use of existing security mechanisms is not sufficient to address the security issues of IoT due to huge scalability and heterogeneity. The plethora of IoT applications and huge amount of data being produced also makes the task challenging. Hence there is need for an enhanced security system for IoT ecosystem. The use of new methods to circumvent the security issues is the need of the hour because every now and then new types of attacks are created. The use of a single approach is not sufficient to curb the security problems of IoT [27]. Hence there is need for a multidisciplinary approach to encounter the security problems. After studying various papers related to the security and privacy of IoT ecosystem, the use of combined data mining and machine/deep learning methods comes out to be the best solution. The use of supervised, unsupervised and hybrid learning strategies from ML/DL is of great use for studying the previous attacks encountered by the IoT system and their prevention by using intelligent methods.

8. **Conclusion**

The idea of Internet of Things (IoT) is making its roots advanced in our day to day life, having a very positive impact on the quality of life. The concept of automation around us is going to open new doors for entrepreneurs and various business giants to explore the markets. Hence it is very important for researchers to address various aspects of IoT intricately like architecture, background technologies and applications. Similarly, various studies also need to be conducted
expanding the challenges encountered in the implementation of IoT.

This paper addresses a systematic review of different aspects of IoT by thoroughly studying various research papers and making an effort to put forward a standardized architecture, collaboration of IoT and other magnanimous technologies like Cloud, Big Data, Block Chain. This paper also studies the dual impact of IoT on industrial growth and various challenges faced in IoT ecosystem. The paper provides a strong attempt to glorify the field of IoT and support more research in this area.

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