Constraints in the IoT: The World in 2020 and Beyond

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Abstract—**The Internet of Things (IoT), often referred as the future Internet; is a collection of interconnected devices integrated into the world-wide network that covers almost everything and could be available anywhere. IoT is an emerging technology and aims to play an important role in saving money, conserving energy, eliminating gap and better monitoring for intensive management on a routine basis. On the other hand, it is also facing certain design constraints such as technical challenges, social challenges, compromising privacy and performance tradeoffs. This paper surveys major technical limitations that are hindering the successful deployment of the IoT such as standardization, interoperability, networking issues, addressing and sensing issues, power and storage restrictions, privacy and security, etc. This paper categorizes the existing research on the technical constraints that have been published in the recent years. With this categorization, we aim to provide an easy and concise view of the technical aspects of the IoT. Furthermore, we forecast the changes influenced by the IoT. This paper predicts the future and provides an estimation of the world in year 2020 and beyond.**

Keywords—Internet of Things; Future Internet; Next generation network issues; World-wide network; 2020

I. INTRODUCTION

The Internet of Things (IoT) is a next generation world-wide network that contains large number of interconnected heterogeneous physical devices, enlightened by [1].

CompTIA's research [2] and M. Swan [3] discussed the estimated ratio of objects connected to the internet to reach 50 billion in 2020. In fact, Cisco estimated the 11 trillion devices per year over 2025 [4]. This high-level connectivity supposed to be delivered by the IoT will clearly play main role in technical advancements, which will open new ways of productivity with more flexibility and customization. Technically, a device in specification of the IoT; is an object in real-time environment implemented with improved capabilities of computation and communication. Theoretically, the IoT is a durable connection of aforesaid objects or devices.

Nevertheless in the way to progress, the IoT faces some technical requirements such as functional requirements, non-functional requirements and design constraints categorized by [5]. Design constraints can be elaborated by the fact that smart things generally regarded as small sized physical devices connected with the Internet, face limitations in terms of IP numbers, packet size, packet loss and alternative paths for connectivity, throughput, power and supported complexity [6]. Furthermore, connected objects vary according to the functionality or purpose they serve. Elmangoush *et al*. [7] explained the heterogeneity and the challenges related to connecting devices that includes scalability, governance and lack of testbeds specifically for Smart Cities. The nature of each object varies according to their size, position and capabilities.
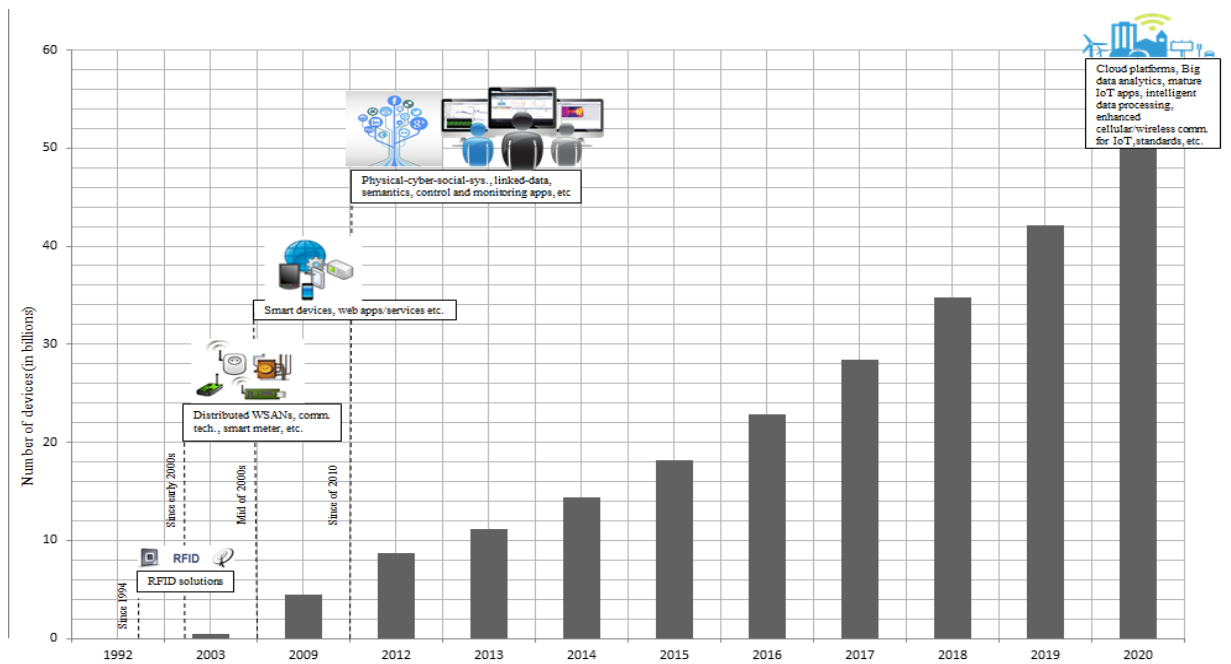
Fig. 1.   Estimated number of interconnected devices obtained from [2][13]

In order to connect aforementioned objects in a network, a unique identification number such as RFID (Radio Frequency Identification) and sensor(s) for their continuous state sensing, are needed. RFID and sensors will enable the objects to interact but due to the huge ratio of objects and their variations creates the scalability and diversity of objects; a major hurdle. This will ultimately address the challenge to create a communication framework in such a way that can handle the scalability and variety of objects to achieve the intended applications that may encompass automation functionalities. Automation functionalities include sensing, acting, locating, identifying etc. analyzed by [8]. Figure 1 estimated the compound growth of the IoT that contains both ratios of existing and expected connected devices, along with their diversity. The curve in the Figure 1 also elaborates that the number of physical devices (in billions) per year is adversely increasing, that addresses both standardization and scalability challenge.

The IoT deployment demands to handle the challenges regarding constraint devices, scalability and diversity security issues. That ultimately leads to the requirement of enabling technologies such as hardware, software and algorithms, standardization techniques, network technologies, communication technologies, power and storage technologies, identification technologies, sensing technologies, data transference technologies, architecture and network relationship management technologies addressed by [9][10][1]. The major limitation involved in the deployment of the IoT regarding these technologies are analyzed by [7] [9][11][12] such as micro software, power and storage need, communication standardization, communication protocols, architecture design, security and network management. Multiple numbers of unique IDs per object need leads to the requirement of infinite number of unique IDs. However, this problem has been solved to some extent by IPv6. Micro

operating systems are needed for unmeasurably small devices. Power and storage is the major requirement for small devices to sustain the reliable connectivity to the IoT. The necessary standardization techniques are required for the communication between diverse natures of devices in a network. Moreover, the considerable fact is that all of the devices or things are not connected to the Internet, all the time. In that case, there is a need to manage an alternative communication path. Therefore, architecture design also faces the barrier of devices' nature in this regard and checks for an alternative way to be connected. Security concerns and network management are also referred as major hurdles in the IoT.

The basic principle of the IoT technologies has been discussed in [10] is a combination of Sensor technology, RFID technology, Smart technology and Nano-technology. Aforesaid technologies are not new but with IoT advancement these technologies are been more focused and enhanced. However, there are lots of challenges with the addition of technical constraints in the way to deployment of the IoT that will be surveyed in this paper.

Contribution of the paper:

- This paper provides an analysis of recent major technical issues that the IoT is currently facing. The taxonomy for categorization of the IoT is provided.

- Moreover, a categorization of the technical constraints and their overlapping factors is also presented.

- The brief survey for technical restrictions of recent papers is presented in tabular form. It is positioned as a survey paper beneficial for wide range of audience such as business strategists, data analysts, researchers etc.

- Furthermore, the technological advancements in the IoT along with their limitations and effects on society are provided to update the readers with recent trends.

- The open social challenges in future are also highlighted in the paper.

- The paper aimed to refine the basic principles needed to deploy the IoT.

- Moreover, the paper provided the estimation on the ratio of interconnected devices to the IoT up to 2026 and ratio of IT jobs up to 2020 based on previous estimations.

The rest of the paper is organized as follow. In Section II, the IoT technical constraints and enabling technologies are analyzed in broader perspectives. Most recent technological advancements related to the IoT are described briefly in section III to introduce the readers with the technological updates. Section IV is about performance evaluation of the technological advancement with their impacts on society and technical limitations. Whereas, in section V remaining open issues related to the IoT are shortly listed. Finally, to provide a short summary paper is concluded at the end in section VI.

II. TECHNICAL CONSTRAINTS

The Internet has been changed from computer-to-computer connection to ubiquitous Internet and now proceeding towards the IoT; that is everything is interlinked with every other thing, anywhere and anytime. It indicates that the IoT will provide bases to initiate a new technological phase soon (estimated in 2020), which will expose new means of opportunities in everyday life. Due to its vast applications, the IoT has been focused and new ideas have been proposed in this regard by many researchers in recent years. Figure 2 enlightened the major areas of the IoT that includes the IoT challenges, the top IoT enterprises, applications of the IoT services and the IoT solutions. However, the paper aims to specifically focus and explore the further categorization of its technical barriers highlighted by Figure 2. This section will analyze the technical constraints that include standardization and policies issues, hardware limitations, gateway systems challenges, middleware issues, the database management issues and security and privacy challenges as described below.

A. Addressing and Sensing issue

In the IoT, every object in real time environment, either it is a living thing or non-living thing, needed to be addressed by a unique identity. [11][12][19][20][21][22] analyzed the addressing and sensing issues in the IoT perspective such as IPv6 adaptation, automatic identification and configuration, participatory sensing, etc. Using sensor technology networks, it is obvious to have large number of nodes that must be addressable separately. On the other hand, the problem is the ratio of objects is far greater than IPv4 addressing scheme. Future estimations predict that it will increase to infinite number of devices or object instead of decreasing [2][4][13]. B. Stockebrand [23] claimed that IPv4 is already outnumbered and all of the IP addresses had been occupied. Therefore, IPv6 was defined by the means of 128 bit which will fulfill the demands of ever increasing IP addresses.

The famous claim about IPv6 is stated as it can assign address to every bit of this world but this scheme still faces the design limitations. The approach cannot be used in a scenario; if RFID tag identifier is 96 bits long. L. Atzori *et al.* [10], analyzed the methodology for this problem in which a separate agent is used for IPv6 IP address as an interface ID. As identified by [24], the transition to pure IPv6 is pretty challenging but it have more advantages over IPv4 scheme such as providing internal security and end-to-end user transparency with the addition of realization of addressing need. However, transition is not that easy, the IPv6 users' needs IPv4 side by side to use important resources and stay connected to existing connection. IPv6 requires a large amount of time to be fully functional as a standalone scheme. It shows that there is a huge gap for mobility support on technical bases. Therefore, mobility management is needed to be focused because of adaptability and scalability issues related to diverse nature of devices in heterogeneous environment.

The order in which address is been fetched correspondingly faces the drawbacks related to addressing technique. As Domain Name Server (DNS) is used for mapping domain name while fetching the IP address of host associated with specific given name but in the IoT, communication must take place between objects rather than hosts. The issue has been addressed by [20][25][26] and Atzori *et al*. [10] proposed that an Object Name Server (ONS) technique can be used at object level communication. In current Internet, the tag identifier mapped on the Internet Uniform Resource Locator (URL), and the desired information is fetched. However, Object Name Address (ONA) should work in both ways and vice versa in the IoT. It should be able to associate the information to a given RFID tag identifier and can also map on in opposite direction. The other issues in addition to addressing is; if the device is connected to Internet all the time then it can be addressable and its state can be sensed. However, due to heterogeneity of devices in the IoT, all of the devices are not connected to the Internet directly according to their nature or some critical security issues. In that case, the devices need some technique to be addressed indirectly and sensed to get updated by its state through some other medium.

B. Networking Issue

In networking, protocols play a critical role for connection and data transformation; as it can reduce the service integration time and cost [7][17]. Network protocol acts as a mainstay for data routing between outer world and sensors. The current Internet is using TCP protocol for transmission at transport layer, which is not feasible for the IoT due to its limitations. There are a lot of existing protocols depending upon different criteria for mobile networking but all of them have drawbacks making them impracticable for the IoT. So there is a need of protocol for efficient handling and processing of data. [9][10][11][27][28] analyzed the major issues related to TCP protocol which can be categorize as:

1) Connection Setup: TCP protocol creates connection first before initiating any data transmission which means, it is connection setup based protocol. It takes considerable time for

creating connection before actual data transmission. It seems unnecessary and time wastage in case of the IoT because the amount of data and time for connection is considerable short.

Furthermore, connection is created between two terminals which is energy and resource taken, so it is not feasible.
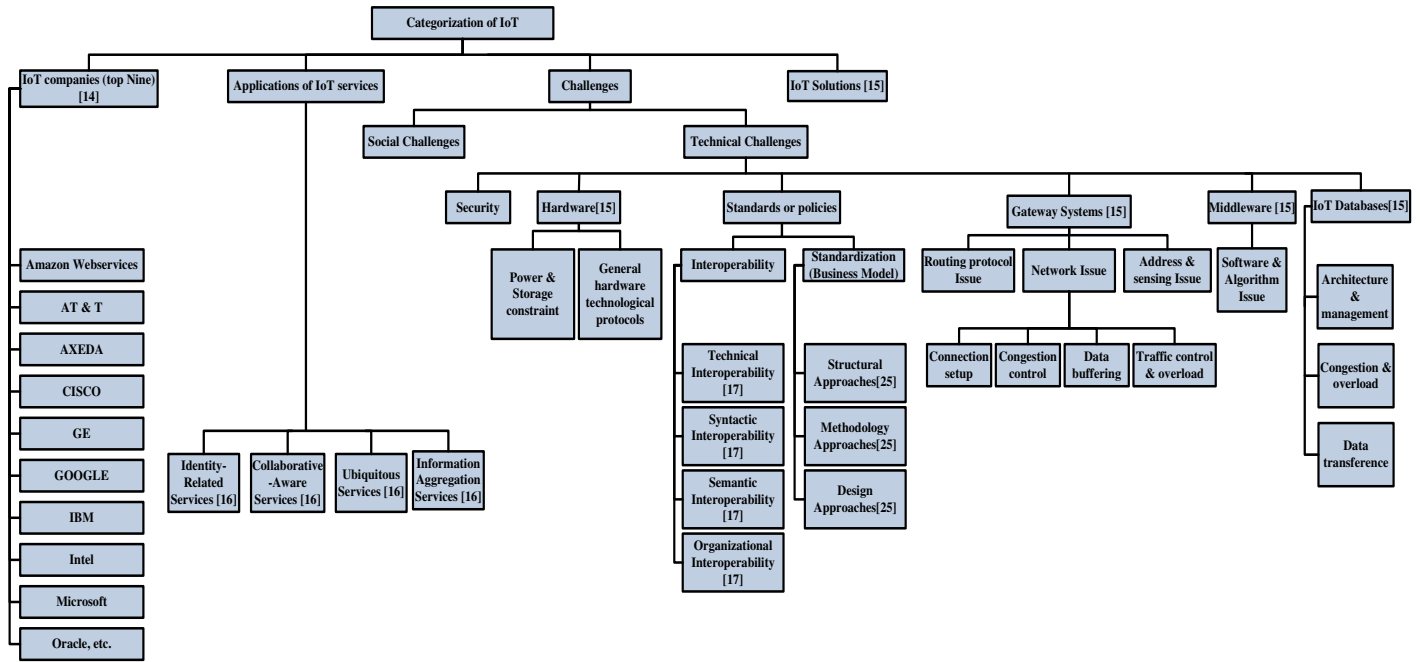

Fig. 2.   Categorization of IoT obtained from [14][15][16][17][25]

2) Congestion Control: TCP protocol is responsible for performing congestion control over both terminals during data transmission, which is not realizable in case of the IoT due to its heterogeneous nature. Most of the time, data to be transfer is of small size and the congestion control in that case is an overload. Moreover, the communication is done between different types of wireless networks and mediums. Congestion control in that scenario will decrease the performance. Thus, the TCP congestion control with its existing state is impractical in the IoT perception.

3) Data Buffering: TCP protocol stores data at both terminals to ensure the secure transmission of data. Subsequently, in case of any damage or loss during the transmission data can be resent. It requires buffers on both ends to store the data that will be very costly in term of both energy and storage for the devices which are small with low storage capacity and very limited battery life.

4) Traffic Control and Overload Issue: Traffic control in the IoT is another challenging task related to networking. It is a smooth transmission in term of traffic control when it is only between sensor nodes in wireless network. But it become complicated when sensors become part of whole network having heterogeneous purposes. In machine-to-machine (M2M) communication, the traffic control is totally different than human-to-machine communication. Moreover, unmeasurable number of devices involve in the IoT will also create overload traffic issues. Therefore, there is a need of characterization of network traffic which totally depends upon application scenarios. Furthermore, the existing network infrastructure is unable to address the high amount of traffic that is going to be generated in near future. Efficient protocol having advance levels of traffic handling and network management are needed to be implemented.

C. Routing Protocol Issue

Vehicle-to-Vehicle (V2V) communication is a type of distributed computation environment, which has huge number of nodes with variable and constrained network topology. However focusing on the importance of routing aspect in V2V communication, S. Agrawal and D. Vieira [11] discussed the two basic ways of routing. One is source routing: in which destination is already defined. Second is hop-to-hop routing: in which only next node address is known. Therefore, hop-to-hop routing is more suitable for V2V communication. Thus, the next best hop can be selected for routing during communication.

Routing protocols like Geographical Source Routing (GSR) use global positioning mechanism, which can cause path uncertainty and route fluctuation. On-Demand Routing protocol use flooding method that can create congestion problem because it sends data to all possible nodes. Various other existing routing techniques like Greedy Perimeter Stateless Routing (GPSR), Dynamic MANET on Demand, etc., have their own limitations and drawbacks. M2M is a key enabler for Smart Cities addressed by [7]. With the advancement of technologies, M2M will require consistent data routing due to the need of high data rates. This is a key challenge to create a reliable routing protocol having high speed transmission and low delivery delay time.
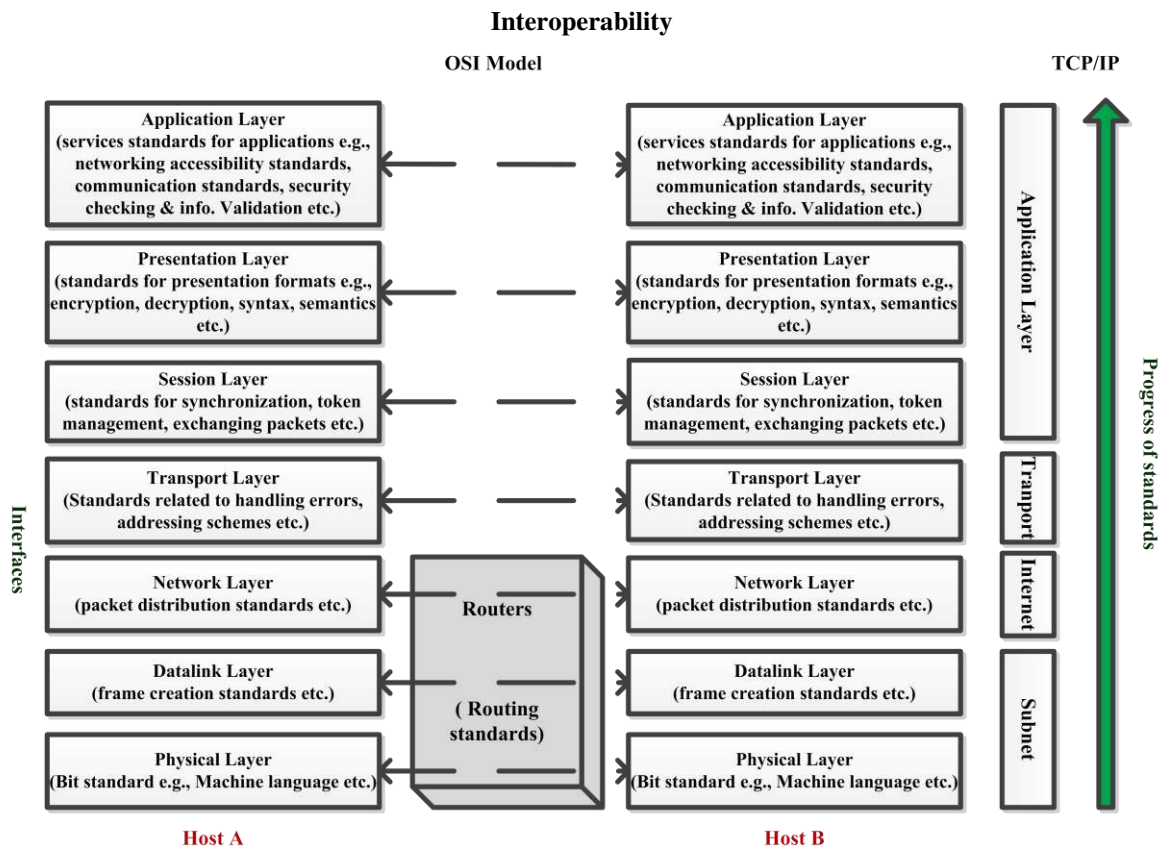
Interoperability

Fig. 3.   Standardization level with respect to OSI model within interoperability obtained from [61] [62] [63]

D. Standardization Issue

The number of items in the IoT is extremely high. Therefore, issues related to representing information, storing information, interconnections, searching, and organizing information produced by the IoT will become very challenging [10]. Different approaches categorized as structural approaches, methodology approaches and design approaches have been proposed to achieve the business model discussed by [18]. In current Internet, application domains are separate, which is making business domains separate and ultimately not meeting the goal of the IoT. Thus, there is a need of standardization techniques to join all separated application domains in a sophisticated manner.

Diversity is an inherited characteristic of the IoT that leads to the major issue refer as interoperability. Whereas, standardization of technologies lead to better interoperability; as interoperability depends upon standards for functions and interfaces expressed in Figure 3. The gap that needs to address is lack of technical interoperability among diverse devices. W. Pollard [29] stress that in M2M communication scenario, standardization techniques provide a middleware to handle communication mechanisms, device management and reachability between end terminals. Moreover, it is necessary to follow standards for devices to work together on the same platform of the IoT. Otherwise the devices will not provide proper services to client. International Organization for Standardization (ISO) provide family of standards, which are gaining popularity [17][30].

M2M communication is leading model toward the IoT but there is precise little standardization work done in this regard. The aim of M2M communication is to connect all the devices, sensors and their actuators abstracting communication techniques. The operation cost for M2M communication is also addressable. Therefore, there is a need of optimized standard interfaces to be made for M2M communication in order to address interoperability and scalability issues related IoT. European Telecommunications Standards Institute (ETSI) is focusing on standardization techniques for M2M communication. Separate technical committee is launched for this purpose to increase the effort speed in European Telecommunications Standards Institute (ETSI). The common issues included are location, addressing, sensor networking integration, naming, charging, Quality of service (QoS), privacy and security, network management, software or application, and hardware interfaces for M2M communication standardization [7], [11], [28], [31], [32], [33].

E. Software and Algorithm Issue

There is a need of common software (in terms of new protocols) and algorithms to provide a middleware base independent of resources and networking function for the connectivity in different environments among diverse devices.

J. Gubbi et al. [12] focus on creation of such distributive application development scenario to build a coherent application. That will support interoperable interaction among M2M communication over a network. In [34], it is focused that the distributive application should be containing self-manageable properties containing self-optimization, self-configuration, self-healing to handle communication in different scenarios.

New micro operating systems are also required that can efficiently function for small devices in terms of energy and power. New password mechanisms should also be introduced to ensure the security and privacy during the communication. In this regard Service Oriented Architecture (SOA) approach has been followed by the IoT [10][21]. Service Oriented Architecture (SOA) allows decomposing the complex systems and monolithic system. This results in well-defined and simpler application development that follow standards during development ultimately facilitates components coordination among each other. This approach also gives reusability of software and hardware components. Perhaps, it also misses the solution to abstraction of details including devices, functionalities and capabilities details. To maintain the position on top levels CISCO claims to provide such software solution that will be highly focused on security concerns by [35].

F. Power and Storage Constraint

The IoT device is constrained by the entity which is in physically monitoring state and the position of the entity is frequently changing without access to power [7]. Most of the devices in the IoT are having considerable small size and are not fixed. Due to their size and frequently changing location property devices are not able to access the power all the time. So the low power consumption is universal constraint of the IoT. Either they use battery technologies or they can use some techniques for taking power from their environment using other devices. Therefore, there is a need of design in which such power consumption techniques or low power consumption schemes are made with long lasting life of devices. Another design issue to be addressed is a requirement of such modular approach that subtracts the need to make a separate chip for each and every application because it is not feasible to create a chip for each and every application. Such high modular approach will combine existing chips within size and power constraint. In [25], some theoretical low power circuit solution is proposed. Nevertheless, this area needs a lot of research and effort without which the IoT cannot be achieved.

G. Architecture and Network Relationship Management Issue

In the IoT perspective, devices have not been expected to sustain their positions. However, the reliable connectivity demands to address and sense the devices all the time. To address huge number of mobile nodes in a world-wide network is also referred as major scalability issue. [7][12][10][19][36][37] analyzed the need to address architecture and network relationship management issue. N. Meghanathan, S. Boumerdassi, N. Chaki, and D. Nagamalai [38] emphasized the need to build architecture with such efficient mechanism that can discover all sensor resources and can register and update new sensing systems in wider network. In [39], the major challenge to the IoT is triggered that "*Who monitors the monitor?*". The IoT is integrating the heterogeneous devices into already defined networks, which is particularly advancement for industrial revolution. The problem is; if the information from machines are stolen or fetched and used for purpose by unauthorized person or entity. The IoT will never stop evolving and ratio of objects will increase with the time. With more devices connected to the IoT will raise the amount of data that required to be managed efficiently. Moreover, it is not possible to cover each and every scenario of the IoT. By customizable sensor technologies the things are able to be monitored by a specific location but the things can be monitored not the devices.

Intelligent networks are needed to be created which can control and monitor each other independently. Another issue pointed by CISCO [40], is data collection especially in Smart Grids Networks, which clearly maps to scalability issue. Other issues related to networking management include Closed-Loop Functioning and Network Resource Preservation. There is a need of such architecture which will able to handle these sort of Ad-hoc networks using different Network technologies (wireless, fixed, mobile etc.), equally and efficiently. Whereas, in [40] CISCO clearly understands the marketing progress in IoT so it is working deliberately hard and proposed new technology named "FOG computing" as a solution to prominent problems. Its practical implementation is estimated up to 2018 by CISCO. In[41], TELIT as a service provider claims to be an IoT global enablement partner. Its focus is on Mobile Network Operation Management and security.
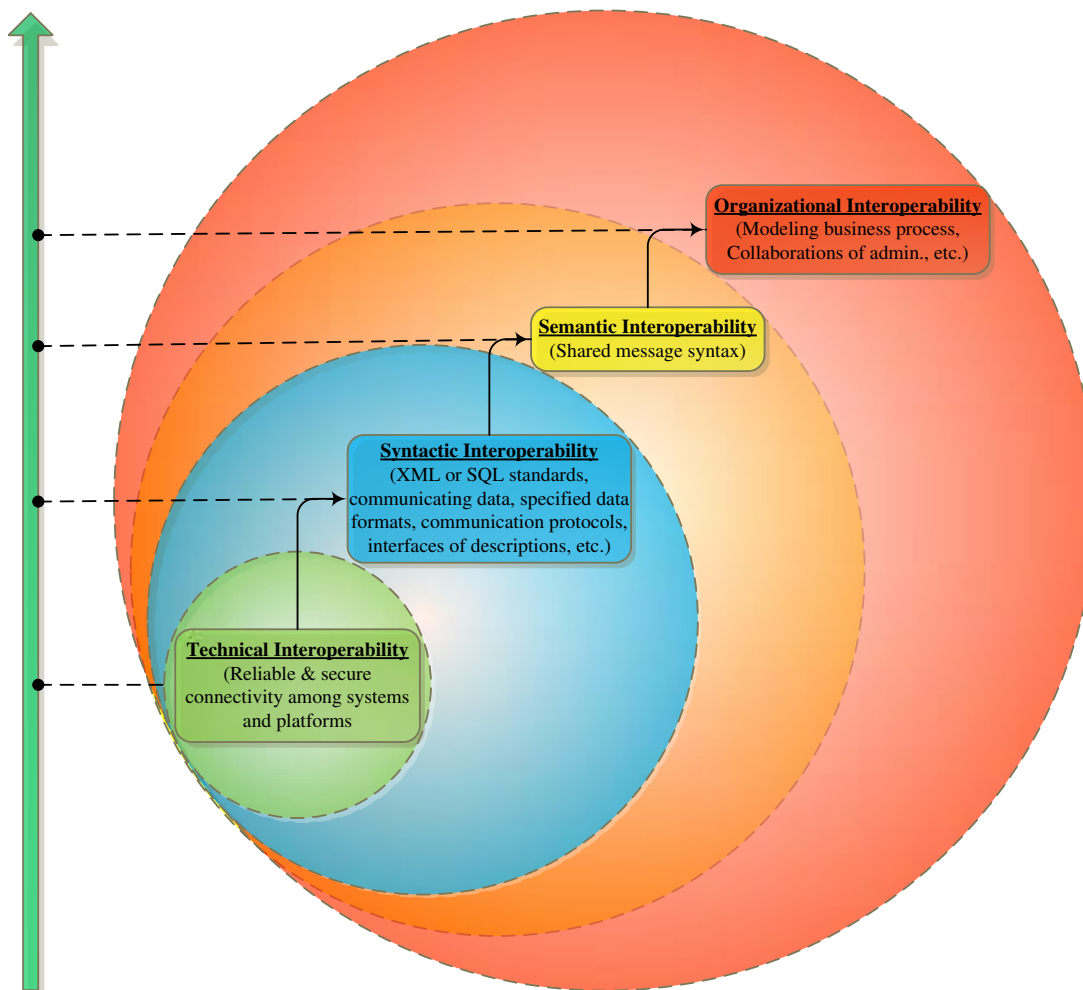
Fig. 4. Bottom-up Layered approach of Interoperability

H. Hardware Issue

Field of Nano-technologies has been quite evolved in recent years but still some software are very large to be handled on such level (in the IoT perspective) e.g., Linux with all features. Furthermore, the hardware issue with power and storage constraint also required to be managed. RFID technology has been researched a lot in this regard, which make system noticeable of small size and low cost [10][22][39][42]. It provides high radio coverage area. RFID sensor network can support computing data, communication and sensing devices abilities in an inactive system. In a real-time critical environment, IoT also needs back-end sensors, networks and infrastructure in case of any failure occurs in the regular IoT network. Now the IT business communities are more focusing on hardware development for the future market competition. CISCO [35], one of the competitive organizations; is claiming to produce such open hardware solution that will be able to work with other hardware components or devices. This means that these hardware solutions will be perfect solution for networking environments and it will provide sound functionality while connected to other devices. Moreover, there hardware and software solutions will be focused on security as security is the major issue in IoT. Such hardware solutions are needed for future

Internet, which can handle all constraints mentioned above and new undiscovered problems because practical implementations are needed to test the IoT environments, which is currently not implementable due to certain limitations for example Smart City.

I. Interoperability

In [17], many organizations including ETSI (European Telecommunications Standards Institute), TIA (Telecommunications Indus- try Association), ITU-T (International Telecommunication Union), OMA (Open Mobile Alliance), GISFI (Global ICT Standardization Forum for India), CASAGRAS (coordination and support action for global RFID-related activities and standardization), CCSA(China communication standard association), etc. are specified. These organizations are specifically working for interoperability issue in IoT and M2M communication. M2M provide base for the IoT architecture as it describes the serviceable components of IoT. Interoperability is also addressed in [30][24][25][45][46] as one of the major key challenge. In [17], different levels of interoperability has been defined.

Figure 4 presents a bottom-up approach, which can also be described as layered approach. Each layer is dependent to the

layer below in some scenario, for example, syntactic interoperability is only possible, if technical interoperability exists so the syntactic interoperability will be the next step when technical interoperability is already implemented and so on. In [17], it is analyzed that there are two major issues regarding technical interoperability. One is the lack of complete reference architecture and other problem is the lack of technical interoperability estimation scope. Whereas, [47]

claimed that technical interoperability can be achieved as technology progressing rapidly but business and semantic interoperability is the more challenging issues. Moreover, [48] stated that in technical area professionals needed to work with business area professionals as partners to achieve the IoT. Business interoperability is the most difficult challenge of all other interoperability.
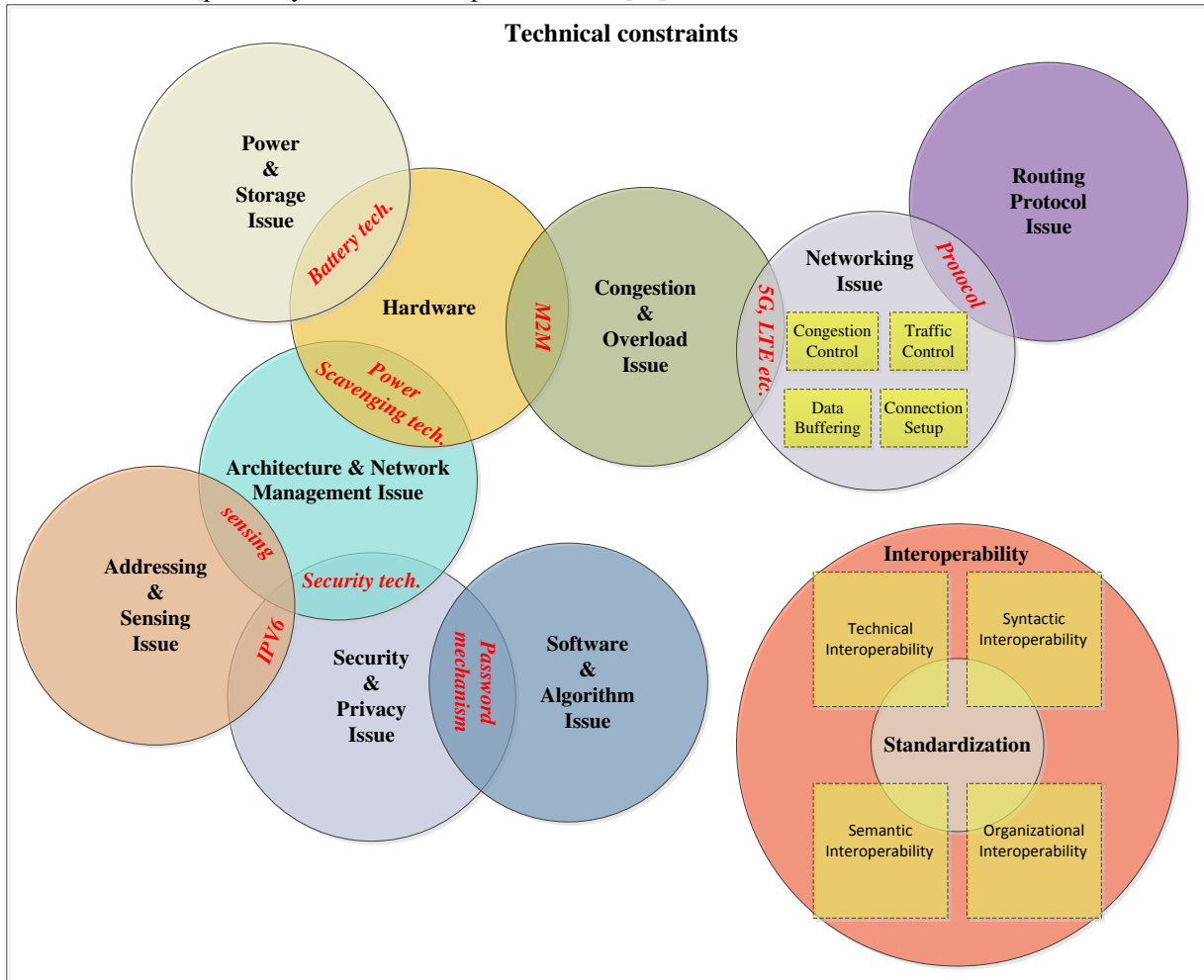

Fig. 5.   Overlapping Technical Constraints

J. Congestion and Overload Issue

Congestion problem occurs when simultaneous messages came from multiple devices eventually leads to extreme overload situation which causes huge effect on network (3GP) which affects the network performance and leads to network failure. This situation can be seen in M2M and V2V communication and it has been researched by [5][6] related to the IoT. The congestion can also be occurred due to server or application malfunction. In [41], solution has been analyzed of congestion and overload issues, which can be resolved by LTE-advanced or existing technologies like LTE high bandwidth networks. One solution to this congestion control is to specify the time duration for connection. Devices can only connect to network when there is no overload and if the network is overloaded then disable all other connections.

Second solution is to reject the connection from devices which create congestion problem.

K. Security and Privacy (Data transference issue)

Security and privacy is one of the most important hurdle of the IoT and it has been recently researched exhaustively by [49][9][50][20][51]. As security and privacy is a completely separate research area but indirectly collaborates with technical constraints therefore this survey does not focus on it but instead it just delivers the main idea. Technically, the IoT will not be applicable until or unless people tend to accept it. And this acceptance is correlated to the guarantee of their security and privacy. Data could not be collected in anticipation of the mistrust of people towards the Internet is cleared. However, the uncertainty of the security and privacy is due to the dark side of the IoT infrastructure. The future

internet will not only affect the IoT users but even non-users will also be targeted, indifferent to the todays Internet scenario.

The digital storage cost is tremendously decreasing, that result to store the information once generated to unlimited time, also included the fact about user's forgetting attitude towards digital data. Ultimately the IoT is providing an environment of great risk to privacy and security by integrating all of this digital data into world-wide network. Privacy and security can only be ensured if a user has fully control over his/her information. A user must know that what personal data is collected, who is collecting, where it is processed and when it was collected. Furthermore, the personal data should only be used by authorized service providers e.g., authorize medical organizations, authorize research institutions, authorize management systems, etc. Moreover, the data should only be stored for restricted time limit under severely need base scenarios otherwise it must be destroyed immediately. But this type of control is nearly impossible in sensor networks and the management authority is also difficult to define for this sort of control. Security constraint has also been focused by [6][18][26][52]. The data transference techniques are not able to control such level of security breaches due to technical limitations related to networking and middleware. Thus, there is a need to create such sort of data transference techniques that will not only handle high-level of security but also ensure authentication and data integrity.

The technical constraints explained in this section are overlapping each other but defined at some level of boundaries. Figure 5 highlighted this fact with the overlapping circles of constraints and red text in shaded areas in the overlapping regions. These overlapping regions show the interconnected behavior of the IoT technical constraints.

III. Most Recent Technological Developments

In this section, the most recent technological developments in the IoT perspective are briefly described. In [53] many recent technologies and their impact on daily lives have been analyzed. Customized services that matched for situation using location information, is implemented by using personal preferences and locating the person position. GPS and Google mapping is used to achieve the function. It can be used for different perspectives e.g., best nearby restaurants, hospitals, institutes, etc. With the use of smartphone, a person can be notified in nearby best restaurants, hospitals, institutions, service providers (Software houses), etc. according to personal preferences and customer or user received reviews.

The traditional Internet converts the world into a form of village but the future Internet is providing services entirely eliminating space constraints. It includes advancements such as smart city, precautionary maintenance system, remote electronics control service, etc. [53]. All electronics and devices are connected with social networking service (also called as social networking site or SNS). It manages real-time statistics e.g., temperature, speed, air pressure, and vibration. The statistics are then analyzed and prediction using data analytics are produced. In Smart City, the integrated CCTV control center recognized instead of human monitoring. If there has been a crime, the system guesses and investigates the suspect's expected escape routes. System notifies the police's mobiles with the related information. It minimizes the crime rate and prevents lives loss or additional damages. In precautionary maintenance system, engine failures in aircraft lead to flight delays due to repairs. This ultimately results in customer complaints at the end, and may even cause major accidents with casualties. For this reason, Rolls-Royce adopted a remote monitoring service by assigning sensors to their aircraft engines. In [46], Rolls-Royce also provides the preventive maintenance service, which eliminates probable intimidations based on its estimations. It could also lead the aircraft engine market by switching from a 'sales business': selling and supporting engines, to a 'service business': charging the rates on service used. Remote electronics control service provides Home Chat facility with the Electronics and mobile devices connected to home appliances. It enables a person to handle home appliances remotely.
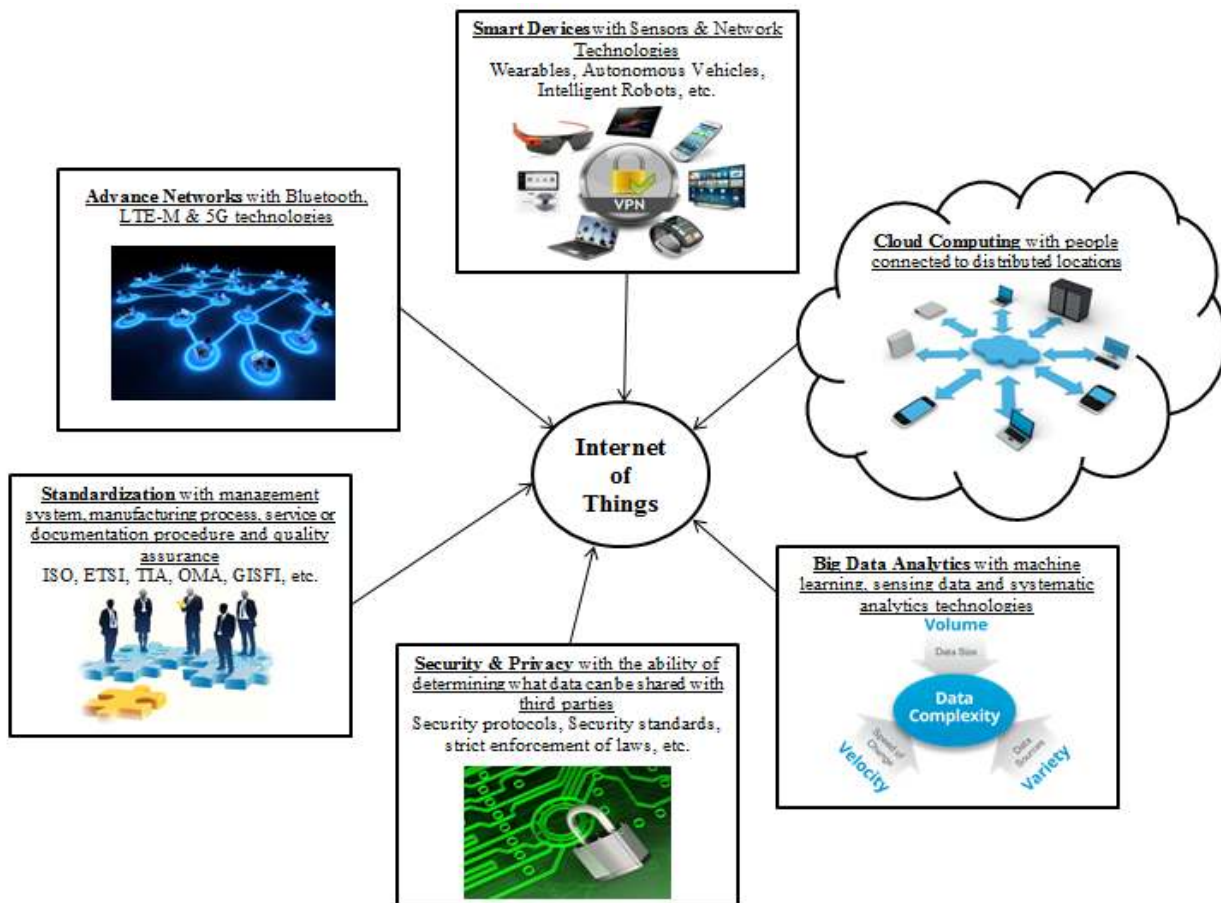
Fig. 6.   Six key factors necessary to deploy the IoT

Optimized management systems with data-based computerization analyze data analytics. GE rail network optimization solution is an implemented system [54]. It reduces extra operational costs (such as a subway train slowing down to wait for the train, in front of it to be removed) because energy and time is needed to reduce speed sharply in keeping a safe distance from other trains and to recover speed. Railroad management is an implemented example of it. The aim of this system is that trains ride smoothly under a systematized system, which results in reducing extra operational costs. GE began monitoring all trains' operational status and locations to automatically determine the right speed for the schedule, with their rail network optimization solution and movement planner system. This change has improved their train speeds by 15 to 20% compared to the average [53].

Uber service is like the traditional call for taxis from the company. 'Transparency' is the key feature in the request process that results in privacy maintenance explained by [53]. Passengers have easy access to nearest available cab/taxi whenever and wherever they want. Personal information of the driver / passengers and reviews from previous passengers are maintained that ultimately provide better customer experience. Moreover, negative reviewers can be constrained from the Uber service for avoiding bad experiences. Smart Payment provides easy use of service.

LittleBits kit, is a hardware set for toys developed in the U.S. [55]. It is an electronic circuit development kit that enables people to develop the IoT lacking any low-level knowledge of development but only with little concept of Input and Output. This is one of the products and services that help even beginners to implement the IoT. The purpose of LittleBits is to provide a system where anyone can build, prototype, and learn about electronics. Each modular component is labeled with a purpose. By chaining them together with their magnetic links more complex circuits started to form. Hooking and unhooking are simple as magnets connect to each module. LittleBits kit can control all ranging from sound to real moving motors, powered by either a 9V battery or a power supply [56].

In Smart School [57], ongoing project involves varieties of multimedia equipment such as electronic pens, digital textbooks, tablet PCs, multimedia, etc. Using these high-tech instruments and integrating them into the system, with high-level connectivity desire functionality is achieved. Smart school based on basic key features of Smart Classes, Smart Information and Smart Management. In Smart class, an Integration of E-Learning environment is achieved by integrating High-Tech equipment. Smart card includes Multifunction (e-attendance, access control, and e-locker) and scalability as an e-cash service. Smart information provides various information such as school affairs, building locations

etc. and increasing security. Smart management remotely monitors and control devices/equipment and automated trouble warning. With such an integrated system, people in remote locations can share their judgments, heighten the quality of teaching resources, and make smart teamwork classrooms for a more proficient class.

TABLE I. TECHNOLOGICAL ADVANCEMENT IN THE IOT AND THE PERFORMANCE EVALUATION

Technology Advancement	Development Techniques	Category	Effect/Benefits on daily life	Limitation
Optimized management systems with data-based automation [53]	Integrated CCTV control centers Sensors and State controlling electronic devices Data analytics	Software Hardware Database management system	Organized system Reduce extra operational costs Improved train speeds by 15 to 20% compared to the average [53]. Network Optimization Solution and Movement Planner System.	Complex data analytics strategies, expensive
Customized services that suited for context using location information [53]	GPS Google mapping	Software Database Application	Notifications for nearby best service providers Personal preferences and customer or user received reviews.	End user info can be wrong
Creating new values by connecting objects [53]	GPS SNS Data analytics	Application	Transparency Improved customer service experience Smart payments and ease of access Avoid and control negativity to prevent bad events	Started to destroy the current market rapidly
Services eliminating space constraints [53]	Integrated CCTV control centers Sensors (temperature, air pressure, speed, vibration, etc.) Social networking service (SNS) Data analytics	Cyber-physical systems Software Management Application	Smart city: Replacement of human monitoring; System predictions expected escape routes; System fast notifications to police's mobile devices; Minimizes the crime rate and further costs. Preventive maintenance system: Minimize flight delays, customer complaints, and major accidents; Remote monitoring services; Preventive maintenance service and eliminates potential threats; Charged as per use. Remote electronics control service: Home Chat facility; Enables to handle home appliances remotely	Data management issue, can handle limited number of devices
E-Marketing / smart marketing [51]	GPS Credit cards	Data mining Database Management system	The return on investment (ROI) is quick; Customer experience improved; Easy Exchange of Sales Data; Instant Customer Analysis; Intelligent Devices That Know They're Dying; Analytical Social Media; Advertisements per interests/ preferences	Privacy issues, Lack of trust from both sides (customer & producer), Destroying current market
Smart School [57]	Varieties of multimedia equipment's High-tech instruments Wireless network	Software	Smart class: Integration of E-Learning environments Smart card: e-attendance, access control, e-locker and e-cash service Smart information: provides intelligent information and increased security Smart management: Remotely monitors and control and automated trouble warning. High quality sharing Enhance the quality of teaching materials	Social effect as due to emotions attachments: humans cannot be replaced by machines at some places
LittleBits [55]	Nano Tech. Sensors	Hardware	No low level hardware or software details are needed Facilitating beginner in development	Expensive
Oracle Solaris 11 [54] [55]	Virtual machines OS Physical domains High level connectivity	Virtualization Hardware Software Management system application	Fulfill business needs Increased efficiency High availability Elastic scalability Rapid deployment, development & management Economic (Pay as You Go) Low overhead & Dynamic Standard version and release of Oracle Solaris on all zones	Limited access control, Privacy & Security issue
Smart Manufacturing [66]	3D printing CAD or Scanning machines	Hardware Software	Cost effective manufacturing Customizable and automatic Time and energy saving Variety of materials are available	Intellectual property rights and criminal or illegal use

Autonomous vehicles [67]	Sensors Actuators High-level connectivity	Real time applications Hardware Database management system	Minimize human errors that can occur while driving Minimize death ratio or damages due to road accidents A person can drive without driving knowledge	Expensive, environmental changes effect performance and in case of accident: who to blame?
Driving Innovation in Health Systems through an Apps-Based Information Economy [68][69]	APIs Sensors Actuators GPS	Database management system Cyber-physical systems	APIs for cost effective health monitoring apps development (FHIR API, SMART API, Research Kit, Health Kit, Google Fit API, Validic API, 2net Platform, etc	Inter-operability
Emergency alert and communication system[10][71]	Sensors Actuators Data analytics	Mobile apps Augmented realties Hardware Management software	Improve relationship between public and private agencies Provide emergency reaction teaching to all employees, not just security workers Manage mechanism and authorizations with secure failover systems	Standardization and expensive
Smarter Highways variable speed limits [72][73]	Sensors actuators Data analytics	Real time application Cyber-physical devices	Automatic sensing Adjustable speed limits	Weather effects may affect the sensing
Smart Farming [9], [74]–[76]	Data analytics sensors	Real time application Cyber-physical devices	Increase productivity Reduce cost and economic Provide notifications before alarming situations	expensive
Wearable devices [77]	Data monitoring apps Sensors	Ubiquities computing Virtualization Hardware	Body stabilizers e.g., Kokoon in-ear sleep headphones High quality stimulated gaming Lifesaving monitoring Remote monitoring for pets Health alarming	expensive

The marketers experienced rapid increase in their sales by using E-Marketing [58]. It is beneficial for both service providers and customers. In E-marketing/smart marketing [59], High-level connectivity using GPS etc. are used. The return on investment (ROI) from E-Marketing can go beyond that of traditional marketing strategies and customer experience improved increasingly. The key features include easy exchange of sales data, Smarter CRM (customer relationship management) with instantaneous customer analysis, Intelligent Devices *"That Know They're Dying"* with their own regular maintenance and diagnostics, predictive social media for customer preferences or demands and 100% CTR (Click through Rate) with no phishing of advertisements. Instead, not only consumer will be saved from time wasting on irrelevant ads but service providers will also be facilitated by avoiding wasting of money on irrelevant ads.

Many other useful developments are in progress in a rapid speed. The top IT enterprises are in competition to achieve more market value in the IoT development race. In future, the IoT is more predictable to take over lives with its innovations.

IV. THE IOT NECESSITIES

In previous section, the recent technological advancements towards the IoT have been analyzed. Table I is providing brief analysis to these recent advancements while considering the related restrictions. By observing Table I, one can get an initial idea about the progress of the IoT and limitations. On the basis of Table I and II; it has been evaluated that the six key factors are necessary to deploy the Service-oriented Internet of Things. Four key factors to deploy the future

Internet: Smart Devices, Advanced Networks, Cloud Computing and Big Data Analytics are already been described in [55]. However, the two most critical factors: Security and Standardization/Policies cannot be ignored. Therefore, this paper analyzes and refine the major key factors to the necessities of the IoT in Figure 6.

The technology advancement analyzed in these areas has improved energy consumption by 50% and increased the battery life by 50% [55]. That ultimately decreases the cost factor involved and rate of errors occurrence. The most important and huge impacts of the IoT on daily life has been analyzed by [53] is that the IoT is replacing jobs and it is switching the whole industrial structure. In Table 1, the technological progressions and their effects are analyzed. The advantages in the IoT world has several associated challenges whereas, the six basic principles for deploying the IoT has been highlighted in Figure 6

V. PERFORMANCE EVALUATION

The paper aimed to analyzing all the papers, books and articles for technical constraints from 2009 onwards. This section provides the tabular summary of recent research advancements. Table II presents the most stressed technical limitations of the IoT. Table II is made on the focus or requirements of the IoT and the technical constraints claimed by the recent researchers. Moreover, it provides a comprehensive summary of all the technical requirements and associated challenges currently being faced by the IoT. It will be helpful for all of the domain individuals related to directly or indirectly IoT.

TABLE II.   COMPREHENSIVE OVERVIEW ABOUT TECHNICAL CHALLENGES OF THE IOT

IoT requirements	Technical challenges	IoT requirements	Technical challenges
Organizational Interoperability [45]	• Standards	Organizational Interoperability [44]	• Standards
E-governance [43]	• Semantic interoperability • Syntactic interoperability • Organizational interoperability • Technical Interoperability	[13]	• Need efficient and interoperable solutions • Cloud-based back end services • Adaptable and dynamic analytics solutions
[8]	• Network and security foundation • Size and scale of IoT providers	[6]	• Privacy, Identity Management, Security and Access control • Standardization and Interoperability • Data deluge
Smart devices [20]	• Scalability • "Arrive and operate" • Interoperability • Discovery • Software complexity • Data volumes • Data interpretation • Security and personal privacy • Fault tolerance • Power supply • Interaction and short-range communications • Wireless communications	[9]	• Identification Technology • Internet of Things Architecture Technology • Communication Technology • Network Technology • Software • Services and Algorithms • Hardware • Data and Signal Processing Technology • Discovery and Search Engine Tech. • Relationship Network Management Tech. • Power and Energy Storage Tech. • Security and Privacy Technologies • Standardization
Internet Protocol Wireless Sensor Network [19]	• IPV6 Adaptation • Mobility • Web-Enablement • Time synchronization • Security • No efficient communication protocol	IoT middleware [10]	• Open issue Standards • Mobility support Naming Transport protocol • Traffic characterization and QoS support • Authentication Data Integrity, Privacy, Digital forgetting
[49]	• Heterogeneity and Scalability • Security and Privacy • Search and Discovery • Ambient Intelligence	[21]	• Identification and Addressing • Internet scalability • Heterogeneity • Service Paradigms
IP smart objects and Service composition [78]	• Recursiveness • Semantic composition • Context-awareness • Hybrid composition • Privacy and security • Resource constraint • Power efficiency • Low-power & Lossy communication link • Data/event-driven services • Asynchrony • Discovery • Management requirements • QoS awareness	Cultural, ethical, socio-economic, but also technological expectations in-formation communication system [22]	• Processing and Handling Limitations • Storage Limitations • Transmission Limitations • Control Limitations • Traffic growth vs heterogeneity in capacity distribution • The current inter-domain routing system is reaching fundamental limits • Scaling to deal with flash crowding • Significant processing power / storage / bandwidth for indexing / crawling and (distributed) querying • Security of the whole Internet Architecture • Support of mobility
Smart home and smart building systems [26]	• Distributor-centric rather than customer-centric • Scalability	Circuits and Systems [25]	• Low power consumption • Highly modular approach • Diversity
[11]	• Standardization issue • Privacy and security issue • Routing protocol issue in V2V communication • Addressing and networking issue • Congestion and overload issue	Internal security and end-to-end user transparency [24]	• IPV6 transition
SmartCities, WSNs & M2M (constraint devices: low computation power, energy, memory)[7]	• Scalability • Governance • Lack of testbeds • Non-Interoperable solutions • No efficient new communication paradigm	[13]	• Need efficient and interoperable solutions • Cloud-based back end services • Adaptable and dynamic analytics solutions
Interoperability [47]	• Semantic interoperability	Light-weight IoT	• Semantic Interoperability

	• Syntactic interoperability • Organizational interoperability • Technical Interoperability	reference architecture [17]	• Syntactic Interoperability • Technical Interoperability • Organizational Interoperability
cloud computing [35]	• Security and cloud computing	M2M standards [28]	• Standardization • Interoperability
Application and usage [32]	• Privacy and security • Standardization	Internetworking [27]	• Congestion Control & Resource Allocation • Network Security
Smart environments [79]	• Standardization and policies	Device and data security [40]	• Nano-electronics • Devices secure management • Security algorithms
[80]	• Device and Data Security • centralized Service Management System(SMS) • secure remote management	RFID tech. [42]	• RFID technology transference to paper or plastic while holding the required productive resolution
[46]	• standardization and synchronization • Privacy • Pervasive and Trustworthy Network and Service Infrastructures • Nanotechnologies, sensor technologies, solutions bridging Nano and micro systems, etc. • Components, Systems, Engineering • Towards sustainable & personalized healthcare • Mobility, Environmental Sustainability & Energy Efficiency • Independent Living, Inclusion & Governance	Interoperability [29]	• Convergence in Technology • Integration of multiple data-sources • Unified Data Map / Ontology as point of reference • Mobility and Crowd sensing • P2P Communication • Data Modeling and Data Exchange • Ontology merging / Ontology matching & alignment • Data/Event Semantic Annotation • Knowledge Representation & related ontologies • Knowledge Sharing • Knowledge Revision & Consistency • Semantic Discovery of Data Sources, Data and Services • Semantic Publish/subscribe & Semantic Routing • Analysis & Reasoning
Plug n' Play smart objects [12]	• Complete Architecture • Efficient energy sensing • Secure reprogrammable networks and privacy • Quality of service (QoS) management • New protocols • Participatory sensing • Data mining for deep learning in terms of the need for adaptive, distributed and incremental learning techniques • GIS based visualization	Enabling technologies, Nano electronics, cyber physical systems, intelligent device management, smart gateways, telematics, smart network infrastructure, cloud computing, ecosystem and industrial applications [31]	• Security • Reliability • Complex integration • Discoverability • Interoperability • Standardization • High data rates • Dense crowds of users • Low latency • Low energy and • Low cost • A massive number of devices • Design of open APIs
Business view of IoT [51]	• Privacy, security and confidentiality • Standards • scalability	IoT Business and cloud computing [33]	• Standardization • Autonomic capabilities • Data operations • Privacy protection
[81]	• Heterogeneous and resource constrained devices • LLN(low power and lossy Network) • Confidentiality, mutual authentication & message origin authentication • Security protocols	Warehousing or future supply chain management [37]	• Integration • Agility • Consolidation • ROI • Standardization • performance guarantees and manager trust
Open systems for IoT [48]	• Data integration • Data automation • Data analyzation for identifying actionable insights • Scalability • Interoperability • Agility • Compatibility	Context-aware deployment of IoT [36]	• Automated configuration of sensors • Context discovery • Acquisition, modelling, reasoning, & distribution • Selection of sensors in sensing-as-a-service model • Security, privacy, and trust • Context Sharing
Security [52]	• Identification/ authentication • Trust • Reliability • Auto-immunity	[50]	• Bootstrapping • Mobility • Scalability • Data processing

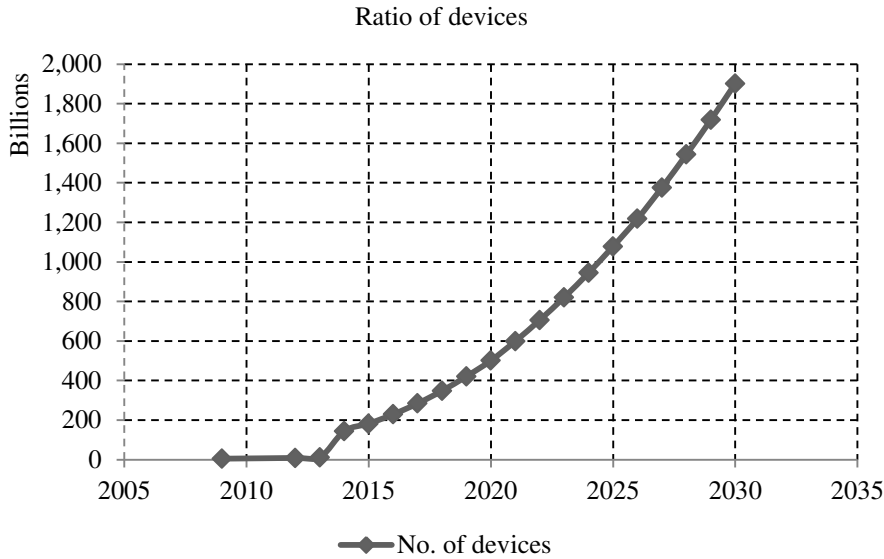|			
	• Privacy • Responsibility • Safety		• Standardization • Protocol and network security • Data and privacy • Identity management • Trust and governance • Fault tolerance
[82]	• Security and privacy • Mobility management • QoS support • Protocols (at both network and transport layer) • Energy limitation and efficiency	[83]	• self-describable and self-contained • privacy and security • limited power supply • communication interoperability • semantic interoperability • syntactic interoperability
Business model [39]	• Devices Integration	IoT ecosystem [18]	• IoT business models and standards
Security [84]	• Routing protocol • Identity management framework		

Ratio of devices

Fig. 7.   Number of devices (in billions) per year

TABLE III.   NUMBER OF DEVICES (IN BILLIONS) PER YEAR

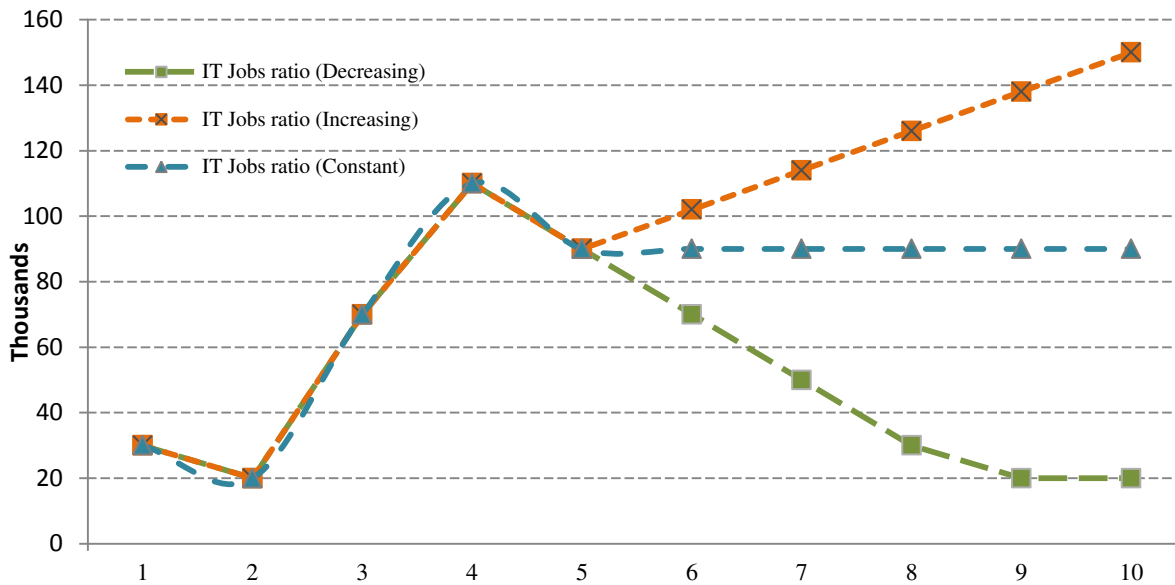| Year	No. of devices in Billion
2009	4.8
2012	8.7
2013	11.2
2014	144
2015	182
2016	229
2017	284
2018	348
2019	421
2020	501
2021	599
2022	706
2023	821
2024	945
2025	1,078
2026	1,218
2027	1,376
2028	1,543
2029	1,718
2030	1,902

Fig. 8. Estimated number of IT jobs per year from 2011 to 2020

VI. THE WORLD IN 2020 AND BEYOND

By analyzing details in previous sections, it can be concluded that the IoT is important enough to change the way of living and even the whole world. The technical constraints analyzed in this paper are the most important and critical ones. These technical constraints are key factors for the future Internet and can enormously affect cost factor for the future devices and technology. The affect the social life style and the way of living in many perspectives will be greatly influenced. An IT research company, Gartner; estimated the human resource demand will be reduced up to 50% by 2018 due to the intelligent machines technology advancements. With the high-speed development in the IoT and its job formation effect, Digital Business related jobs are also predicted to grow up 50%. Repetitive and life-critical work can be replaced by the IoT services. Moreover, Automation functionalities as a key feature of the IoT made it possible to take over data analysis. The industrial structure is creating new values by changing the whole infrastructure and destroying the traditional system revenues. Enterprise value of Uber was analyzed as $45 billion in December of 2014. The Wall Street Journal has analyzed the abrupt growth and estimated it to be $50 billion in May of 2015. The opportunity of existing industrial dominators could be threatened by novel outstanding ideas' innovators, is getting higher.

TABLE IV. NUMBER OF JOBS (IN NUMBER) PER YEAR

Year	IT Jobs ratio (Decreasing)	IT Jobs ratio (Constant)	IT Jobs ratio (Increasing)
2011	30000	30000	30000
2012	20000	20000	20000
2013	70000	70000	70000
2014	110000	110000	110000
2015	90000	90000	90000
2016	70000	90000	102000
2017	50000	90000	114000
2018	30000	90000	126000
2019	20000	90000	138000
2020	20000	90000	150000

If the ratio of devices connectivity is closely observed up to year: 2020 then the number of devices in next year's up to 2026 can be estimated. Figure 7 shows the prediction on the common increasing ratio among previous years' estimations. However, the Table III shows the statistics for assumptions of this paper; the gray shading color highlights the calculated assumptions. Indirectly, the number of devices per year is affecting the number of IT jobs per year. In contrast, the IT jobs are not completely down falling but their average value is not increasing as well. Figure 8 demonstrates the estimated ratio of IT jobs over years. It can be increasing, decreasing or constant amount of IT jobs according to the observation of

previous years' ratio. Overall analysis for the future Internet era clearly delivers the fact that successful companies or organizations will be those, who will provide some innovative technological ideas. The others will be just doomed out economically.
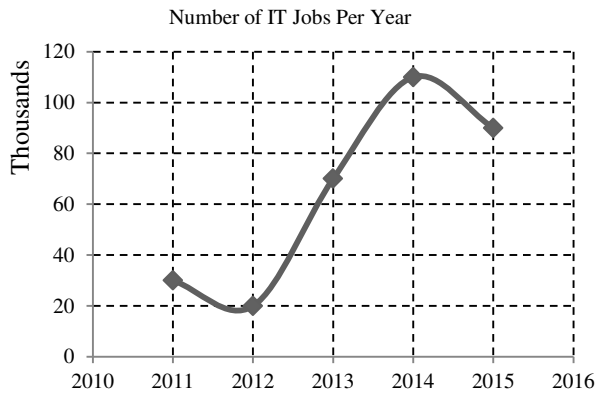

Number of IT Jobs Per Year

Fig. 9. Number of jobs (in number) per year

The statistical data obtained from [60] shows the number of IT jobs in recent years (up to 2015). The data has been analyzed to estimate the ratio of IT jobs in future (up to 2020). The aforesaid ratio has been plotted in Figure 9 whereas, Table IV shows the statistics. The three variations of IT jobs in Figure 9 shows the three assumptions for increasing (highlighted by green color), decreasing (highlighted by orange color) or constant rate (highlighted by green color) of IT jobs. These assumptions are being calculated on average ratios of recent years. The quick analysis of IT jobs against advancement in IT shows that average rate of IT jobs is down falling and not increasing with the rate of the IoT advancements. The reason behind down falling of IT jobs are vague but can be justified by keenly analyzing technology advancements. With the rapid growth in automation and artificial intelligence properties in industries eventually minimizing the human resource factor needed to operate and maintain the environments. The industrialization became more successful entity as compare to other government level jobs. That results in privatization effect, which ultimately goals more work with fewer jobs.

Another major factor involved for discussed downfall is the increased ratio of population. Moreover, young and educated people belong from urban areas or less developed areas moves to rural or developed areas. This ultimately increases the competition for better opportunities as per the life standard are changed. The IoT as advancement in technology is also playing major role in changing life standards of society.

VII. CONCLUSION

The concept of the IoT is maturing rapidly and soon we will be seeing the world-wide interconnected network, integrating every physical device with other devices. The IoT has been focused exhaustively in recent years due to its wider applications such as eliminating space, reducing cost, saving energy and intensive monitoring. This paper highlighted the core areas of the IoT and specifically targeted the technical constraints that act as critical hurdle in the way to deploy the successful IoT infrastructure. We categorized these challenges in security, hardware, standards, gateway systems, middleware and the IoT databases etc. Open issues to the IoT are also enlightened that are required to be addressed by the researchers and other stakeholders of the IoT. Moreover, our future predictions will help the concerned parties to prepare for the IoT accordingly. In future, we aim to provide solutions about the open issues to the IoT.

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