ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Internet of things: Architecture and enabling technologies

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ARTICLE INFO

Article history:
Received 12 February 2020
Accepted 23 April 2020
Available online xxxx

Keywords:
Enabling technologies
IoT
RFID
Sensors
ZigBee

ABSTRACT

Internet of Things is transforming real devices to smart intelligent virtual devices. In IoT day today devices of daily use are manufactured along with sensors which are capable for identification and sensing. They can be networked, are capable to process, can interact with other devices through Internet. IoT objective is to connect almost everything under a common infrastructure. This helps to control devices and will keep us informed about the status of devices. The paper aims to give Internet of Things overview, architectures, enabling technologies and their applications. It presents latest trends, current state, recent developments, challenges, security, privacy, applications of IoT and future research directions.

Selection and peer-review under responsibility of the scientific committee of the 3rd International Conference on Science and Engineering of Materials.

1. Introduction

IoT represents the futuristic computing and communications technology. Its growth relies on innovation in different technical areas like wireless sensors and nanotechnology. The framework that allows device to device communication through Internet has brought more devices online. It allows them to be connected and engaged in the web as an enormous network of devices. IoT has made a global network which supports ubiquitous computing as proposed by Bandyopadhyay et al [1]. The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction as proposed by Rouse, Margaret et al. [2].

Lalit Chettri and Rabindranath Bera et al. [3] focused on IoT applications in 5G system in their research paper a comprehensive survey on Internet of Things towards 5G wireless systems. They also highlighted what kind of research in IoT and 5G is contributing in different industries? Dong, Z., Yian, Z., Wangbao, L., Jianhua, G., Yunlan, W. et al. [4] proposed object service provision in Internet of Things. An Intelligent trust evaluation scheme in sensor cloud enabled Industrial Internet of Things as proposed by Tian Wang, Hao Lao, Weijia Jia, Anfeng Liu, Mande Xie et al. [5]. They proposed mechanism to evaluate the sensor nodes from their communication behavior and sensor nodes. They highlighted the sensor nodes trustworthiness and reduced consumption of energy. Context awareness and ubiquitous computing are essential for IoT as proposed by Jara et al. [6]. A variety of machine learning techniques are used in IoT like, support vector machine, regression, random forest, convolutional neural networks, and variational auto encoder as proposed by Mohammadi M., IEEE Communications Surveys and Tutorials et al. [7]. IoT networks are distributed in nature. It is common for each IoT device to discover who is the neighbor. Battery capacity is a major limitation of IoT devices. A neighbor discovery protocol was proposed that achieves low discovery latency and low duty cycle. The proposed model is generic as it is used for analyzing existing NDPs as proposed by Zhong Shen, Hai Jiang, Qingkuan Dong, Baocang Wang et al. [8].

2. Paper structure

2.1. The structure of paper is as under

Section 2 contains Chronological time series, Literature Survey and Requirements for IoT. Section 3 details key enabling technologies and architecture for the Internet of Things such as Radio frequency identification devices, sensors, actuators, Electronic Product Code, Barcode, ZigBee, Bluetooth, Near Field Communication, Cloud Computing, Networking Technologies, Nano Technologies, Micro Electro Mechanical Systems Technologies, Optical Technologies, Wireless Networks, Big Data, Artificial Intelligence and Machine Learning. It also highlights the Software, Middleware, Searching, Browsing and Internet Protocol. Section 4 summarize the paper and presents the conclusion.

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https://doi.org/10.1016/j.matpr.2020.04.678
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Selection and peer-review under responsibility of the scientific committee of the 3rd International Conference on Science and Engineering of Materials.

Please cite this article as: P. Goyal, A. K. Sahoo and T. K. Sharma, Internet of things: Architecture and enabling technologies, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.678

Table 1
The Chronological Development and Applications of IoT.

Year	Chronological Development
Kevin Ashton 1999	Proposed the name Internet of Things. He was Director, Auto-ID Center, Massachutes Institute of Technology
Neil Gershenfeld 1999	Highlighted IoT principles in the book entitled "When Things Start to Think"
MIT Auto ID Lab 1999	Was founded by Kevin Ashton, Sanjay Sarma & David Brock. They helped for developing the Electronic Product Code
LG 2000	LG launched the world's first smart refrigerator in June 2000 named the Internet Digital DIOS
The Ambient Orb 2002	Rose cofounded Ambient Orb Devices in 2002. It was created in Media Lab of MIT which has taken the initiative for embedding smart information in devices of daily use. New York Times Magazine named it as the best innovations of the year. The orb can be placed on the office desk. It is a financial tool. It changes colors to track the stocks performances. It glows yellow when market is stable. It glows green when stocks are soaring. It turns to a deep scarlet means declining. This is ambient information to monitor everyday data. You come to know what exactly is going on as the information is around you. Smart phones with personalized ring tones inform us who is calling.
US dept. of defense2003-2004	RFID is used by the US dept. of defense on massive scale in its Savi program. Wamart the largest retailer used RFID in their business by embedding tags on its products.
The UN's International Telecommunications Union ITU 2005	It coordinates global telecommunication networks & services. It published its report "Internet of Things at the World Summit"
European Union EU 2008	Recognition by European Union. First IoT conference organized
A group of companies 2008	Launched Internet Protocol for Smart Objects for promoting usage of IP and also for enabling Internet of Things. They advocated for use of IP networked devices in consumer, energy, healthcare and industry related applications.
The FCC 2008	Federal Communications Commission voted by 5–0 for approving and opening the use for unlicensed spectrum also known as white space spectrum
US National Intelligence Council 2008	Submitted its report entitled "Six civil technologies offer the potential to enhance or degrade US power over the next fifteen years". These technologies included IoT devoted towards enhanced and improved connectivity of people and things. It will be having potential impact.
Cisco's Internet Business Solutions Group IBSG 2008–2009	IoT came into existence between 2008 & 2009 when "things or devices" were getting Internet connected
Chinese Premier Wen Jiabao 2010	Proposed IoT as a major breakthrough for sensor networks. IoT will help the chinese industry and planned to make investments for its rapid growth
IPv6 public launch 2011	This protocol was used for calculating the address space needed as per the address plan. It allowed for 340 282 366 920 938 463 463 374 607 431 768 211 456 (2^{128}) addresses to access the public internet using a single IPv4 address.

2.2. Internet of Things

Internet of Things is open exhaustive extensive network of smart devices which possess capability to share resources, data, auto organize, have the capacity to act and react as per the changes in the dynamic environment. IoT emphasizes mainly on "Internet" and "Things". Internet is a global computer network which utilizes a standard Internet protocol for serving billions of users. According to Global Digital Population, as of 2019 there are 4.48 billion Internet users. This signifies 58% of the global population is accessing Internet. China ranks first and India second in highest number of Internet Users. "Things" are real objects which can be living things such as animals, birds, insects, human beings, trees and plants. Things can be non living like television, refrigerator, cars, security cameras and mobile.

2.3. Chronological time series

The chronological developments in the area of IoT and its applications are depicted in Table 1.

2.4. Literature survey

The aim is to give Internet of Things overview, architectures, enabling technologies, their applications. It presents IoT literature overview, trends, current state, recent developments, challenges, security, privacy, applications and future directions. Aggarwal et al. [9], Chui et al. [10], Conti et al. [11], Gluhak et al. [12], Huang and Li et al. [13], Liu and Zhou et al. [14], Mainetti et al. [15]. Internet of Things social resources are deeply integrated for different applications. Social networking, medical services, video surveillance, car networking and other forms of IoT Social service model affect daily lives of people. IoT search is used to find accurate information quickly to meet user's real time search needs. IoT search requires massive amount of information, like social relations, personal health and location information. Theoretical, technical and methodological guidance for IoT search access control mechanisms are required. The future development direction of access control in the age of IoT is proposed by Jing Qiu, Zhihong Tian, Chunlai Du, Qi Zuo, Shen Su and Binxing Fang et al. [16]. Integration of Internet of Things and cloud computing is presented. The issues & challenges of such integration are analyzed. Combination platforms, applications, proposing major areas for boosting integration of cloud and IoT by Motahareh Nazari Jahantigh, Amir Masoud Rahmani, Nima Jafari Navimirour and Ali Rezaee et al. [17], Stuckmann and Zimmermann et al. [18], Tan and Wang et al. [19], Xu et al. [20]. Please refer to Table 2 for more detailed information.

2.5. Requirements for implementation and deployment of IoT

Requirements for implementation and deployment of IoT are as under:

(a) Dynamic resource allocation
(b) Real time requirements
(c) Exponential hike and advancement in demand
(d) Availability of all applications
(e) Data security and privacy
(f) Energy efficient
(g) Execution of all the applications from near to far users
(h) Access to open inter operable cloud

Components required for coherent, continuous and uniform IoT are as under:

(a) Hardware – is any physical component of a system comprising of sensors, actuators, communication networks & hardware.
(b) Middleware – is core component of automated and customized platforms. It serves as a bridge amidst database, operating system and applications. It comprises of storage on demand and various other tools for computing and data analysis. It is cloud based and uses big data analytics

Table 2
Summery of Works Presented.

Ref.	Authors	Summary of works presented
[21]	Lianos, M. Douglas, M	Proposed that growth in IoT is primarily due to the requirements of corporations. This stands to be immensely beneficial due to foresightedness and predictions which can be made. It makes it affordable to track and follow all the devices connected through the internet commodity chain where these devices are embedded
[22]	Ferguson, T	The ability of coding and tracking the objects has made companies efficient by speeding up processes thereby reducing errors and prevention of thefts. With the help of IoT complex and flexible organizational systems were incorporated
[23]	Want, R	Proposed Near Field Communication technology
[24]	Biddlecombe, E	Describes IoT as a global community where anything is connected anywhere. The device connected communicates in smart way. We think of always connected to the world through Smart phone, Laptop, Computer, Server and tablet. The sensors and actuators which are embedded in devices are connected via wireless networks. They utilize Internet Protocol which is used in Internet. These internet connected things or devices generate extremely large data which flows to the computer for analysis.
[25]	Shao, W. Li, L	Proposed that IoT integrated Radio Frequency technology with sensor technology as hardware resources of the Internet. IoT is one of the best upcoming technologies in the field of computing, communications and networking. IoT is widely being adopted for its growing use and various applications. They also analyzed supporting and enabling technologies of IoT, like communication, information, transmission, reception, intelligence, controlling and analyzing technology
[26]	Weber, R.H	Exchanged views on various issues and challenges in IoT like privacy, security, governance and legality. They analyzed how legal framework and governance can be implemented to sort out and tackle these issues
[27]	Atzori, L., Iera, A. Morabito, G	Reported distinctive views of IoT. They addressed dominant issues such as tracking, identification technologies, wireless, networks, sensors, actuators, intelligence in devices and communication protocols for smarter devices.
[28]	Weber, R. H. Weber, R	Analyzed the legal aspects arising due to IoT. They also exchanged views on its requirement for ensuring security and privacy of users.
[29]	Zhu. Q. Wang	Proposed IOT gateway which is based on protocols like Zigbee and GPRS. They have taken into consideration the requirements from telecom operators, industrialists, manufacturers and service providers. This system presented transmission of data through wireless & mobile communication networks. They highlighted different WSN protocols, protocol mapping and control functions of sensor networks.
[30]	Schaffers, H., Komninos, N	Explored how partnership and cooperation strategies are used for establishment of regional innovation systems. This is for experimentation and validation of IoT related services.
[31]	Kosmatos, E.A., Tselikas, N.D	Proposed that things can be anything, device or person which can be uniquely identified. It can be easily distinguished from the others. Day today daily use devices, technically advanced equipments, gadgets, electronic devices. Things which are not electronic are furniture, food, clothes, materials, product, parts, merchandise, special items, artworks, landmarks, monuments, and all the varied collection of commerce, culture, composure and style. IoT is rapidly advancing and considered to be the most hyped technology concept. IoT has managed to attract attention by projecting the networked physical objects worldwide connected using global infrastructure. This is enabling connectivity every time, everywhere for everything and for everyone.
[32]	Kopetz, H	Explained how the IoT enabled devices provides cooperative and collaborative services. These connected devices utilize data from various sources and provide services that are much better than the services which are provided by an embedded system which is isolated.
[33]	Gigli, M. Koo, S	Proposed that IoT is such massive and wide technology that it has no uniform architecture. To implement the concept of IoT broadly it should consists of a combination of sensors, actuators, software, networks, communications, computing technologies and protocols all with a uniform architecture
[34]	Razzak, F	Highlighted that IoT allowed the users to connect different devices to internet and bring them together in the cyber world. This breakthrough is achieved by various connecting and adjoining technologies like NFC, Barcode and RFID. These technologies allowed devices to be individually identified and connected through the internet
[35]	Evans, Peter C	Predicted that IoT will outdo and exceed market of computer, tablet and smart phone. The market of smart devices like consumer durables such as television, refrigerator, wearable's and vehicle will become equal to the computer, tablet and smart phone market by 2018. The operational efficiency and profitability will improve with the usage of home devices with embedded connectivity. The cost savings are estimated to be around $15 trillion over the next twenty years
[36]	Forrester Consulting	Predicted that total devices connected through internet worldwide will be exceeding eighteen billion by year 2018. It will be including vehicles, smart consumer durables and wearable's. The shift towards connected smarter world is affecting almost everyone. IoT is making smart home, smart buildings, smart city, healthcare, agriculture, telecommunication, utilities and finance, manufacturing, industry, supply chain, logistics, automobiles and transportation. Embedded development is also changing leading to a completely new smarter world of inter connected things. Most of the companies have already deployed IoT. Others are also moving forward to deploy it within next two to three years as per survey report of Zebra Technologies and Forrester Consulting. 68% of the companies have already deployed IoT. 14% companies will go for IoT in another two to three years. 7% are also planning for using IoT after six to seven years whereas 11% are still uncertain to use IoT
[37]	Nunberg, G	Described Internet as a network of networks which comprises of academic, business, corporate, private and public networks. These networks are connected together using extensive array of

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Table 2 (*continued*)

Ref.	Authors	Summary of works presented
		wireless, wired and optical networks forming a complete infrastructure for networking
[38]	Gubbi, J., Buyya, R., Marusic, S	Proposed the requirement for convergence of Wireless Sensor Networks. They also proposed cloud based network for worldwide implementation of IoT.
[39]	O'Leary, D.E	Investigated how connected devices and nodes in IoT generate large volumes of Big Data. How this big data is analyzed for producing semantic signs. They also highlighted big data importance and its use in Internet of Things (IoT) & Internet of Signs (IoS)
[40]	Bellavista, P, Corradi, A, Cardone, G, Foschini, L	Proposed that universal, ubiquitous, intelligent, smart environments, which possess (MANET) mobile adhoc network or (WANET) a wireless adhoc network, will produce ample opportunities in urban areas resulting into the growth of IT sector. Wireless Sensor Networks and Mobile adhoc networks union and merger will result into growth and development of IoT, networks, communication, architecture and new protocols. It will be having very high potential for various diversified applications in different domains. They have experimented and validated the proposed solution and results have proved its effectiveness and feasibility.
[41]	Ali Nauman, Yazdan Muhammad Amjad, Ahmad Qadri, Yusuf Bin Zikria, Sung Won Kim Muhammad Khalil Afzal	Proposed that increase in multimedia on demand traffic has shifted the (IoT) from scalar to Multimedia Internet of Things (M-IoT). IoT devices are having constraints in terms of computing, energy, storage, size, and memory. They provided survey of M-IoT with emphasis on protocols, architecture and applications. They highlighted importance of Quality-of-Service & Quality-of-Experience. They explained cloud computing, event processing, Fog/Edge computing, feature extraction and Software Defined Networks. They presented the need of Physical-Medium Access Control protocols and better routing
[42]	Jayavardhana, G., Marusic, S. Rajkumar, B., Palaniswami, M	Described garter's hype cycles for information technology in different domains for tracking the evolution, adoption of new technology, acceptance, maturity, time of adoption, future potential and impact of technology on the applications. In garter's graph X axis represented time & Y axis represented expectations. They predicted that time of adoption of IoT by the market is around ten years and IoT will be recognized to be top emerging technology.
[43]	KellySurya Mukhopadhya	Demonstrated implementation of IoT with the usage of ubiquitous sensing system to observe domestic conditions. They presented details regarding intercoupled devices and machines for tracking and controlling various attributes using sensors and flow of data and information through the network.
[44]	Ortiz, A.M. Hussein, D	Highlighted that like Internet has changed the way of our living to its best IoT will also be having a similar great impact on the society. It will bring major change in improving quality of our lives. Internet is a driving force for the IT industry starting in 1969 from Arpanet to now active and extensive social networking with a predicted fifty billion IoT devices by 2020.
[45]	Zanella, A. Bui, N	Analyzed that IoT devices are small and simple. They are not using complicated (SOC) Systems on Chips. They do not require the leading edge technology. The cost of development is very low. IoT offers very wide range of applications like smart homes, vehicles, smart city, agriculture, infrastructure, environment control, fleet management. IoT has extended itself to an era where billions of devices are internet connected. These devices sense and collect data, information, communicate and share them via networks
[46]	Tony Danova	Highlighted that the interconnected devices keep on sensing and gathering data on regular basis. They analyze the collected data to extract useful information. On that basis of this information it controls and initiate suitable action thereby making the devices smart and intelligent. This intelligence is used for decision making, planning and management. IoT is expeditiously changing our lives, from smart refrigerator, smart watch, smart home, smart infrastructure to smart vehicles. IoT has changed almost everything in our lives. How we purchase, enjoy, work and keep fit. IoT has become Internet of Everything (IoE)
[47]	Stankovic, J.A	Analyzed that the data transfer and exchange of information among devices can take place directly without human intervention. Thus the IoT applications are growing exponentially. Generally IoT applications are classified into enterprise and consumer. Consumer incorporates smart television, refrigerator, security cameras, lighting, home automation, smart wearables and meters. Enterprise involves vehicle management, security, employee tracking, fleet tracking, infrastructure, warehouse, supply chain, monitoring of pollution and wind pressure. They highlighted that wireless networking infrastructure comprising of base station, hardware, integrated servers, management consoles, software and services enables connectivity. It is responsible for communication, networking, management and operations and helps in monitoring and tracking.
[48]	He, W., Da Xu, L Yan, G.	Highlighted that IoT integration with cloud computing has encouraged the growth and development of IoT. Use of cloud computing has resolved various open issues, problems and challenges faced in transportation, grids and energy. They proposed a new vehicle operating on cloud based data platform.
[49]	Sanchez L., Munoz L., Galache, J.A., Sotres, P., Santana	Described the development, design and deployment of IoT experimentation in a metropolitan named Santander city. They demonstrated and validated the deployment of network architecture on a very large scale IoT Testbed. They also discussed the functionalities of testbed and provided solutions for implementation of different components of IoT.
[50]	Porter M.E Heppelmann, J.E.	Discussed that there are tremendous growth opportunities for connected products and the new technologies redefined their functionalities and reshaped the industry. They also discussed the different case studies for examining the effect of intelligent, smart things on the supply chain and logistic structure of Industry. They also proposed new improved structure and supply chain for industry and novel strategic choices. They also examined the impact of value chain and various organizational issues.
[51]	Kuojaite, P., Narbutaite, L. Bruzgiene, R., Adomkus, T	Presented a brief overview and survey of different architectures of Internet of Things. They highlighted that these architectures are capable of improving the understanding of related technology, methodology and various tools. They also facilitated the different requirements of the developer and summarized the state of various architectures in different domains.
[52]	Yang, S.H	Discussed various design challenges faced in IoT. They presented different methods to integrate

Table 2 (*continued*)

Ref.	Authors	Summary of works presented
		the Wireless Sensor Networks with the Internet.
[53]	Schwartz, M	Demonstrated and discussed different dummy projects of IoT.
[54]	Henderson, B	Discussed the different issues and challenges in IoT. They also highlighted the network overheads
[55]	Zanella, A., Castellani, A Bui, N.,	Provided comprehensive overview of current scenario IoT. They highlighted sensor networks enabling technologies reviews of IoT. They discussed the different architecture and protocols for an urban IoT and pointed major challenges. They also presented various best practice guidelines and technical solutions which were used during IoT deployment on an island of Italy.
[56]	Lee, I., Lee, K	Presented different IoT frameworks which are very important for deployment and installation of IoT based eproducts. They also discussed miscellaneous domain of IoT which are generally used for (CSAT) customer satisfaction and enterprise applications. Customers have different types of expectations. Satisfaction level varies from customer to customer. (CRM) Customer relationship management is another approach for managing the company's interaction with customers. It use data analysis techniques, gather and analyze purchase history of customer and measures customer satisfaction. Various data mining techniques are also highlighted
[57]	Wortmann, F. and Fluchter, K	Highlighted the pace with which the IoT is advancing and achieving growth, development and gaining popularity. They have mentioned the facts about IoT and also estimated the IoT future market value and growth
[58]	Riggins, F.J. Wamba, S.F	Proposed that healthcare services, operational productivity, patient experience will improve with the integration of IoT devices with mobile applications. These healthcare devices and mobile applications related to telemedicine, telehealth, medical reference, fitness and wellness applications will provide good results in smart healthcare through (MIoT) medical Internet of Things. Healthcare is major application domain of IoT. A patient having an ID card, which is scanned to generate all history, medicine, treatment, reports and all details related to his or her health. Patient's health can be easily monitored with help of IoT. It will also help in reducing cost and provide economical care. IoT enabled medical devices will be having a great impact on healthcare and life sciences.
[59]	Chiang, M. Zhang, T	Presented the fog computing, its different issues and challenges. With wide deployment of IoT applications, cloud computing faces issues and challenges like security, low capacity, high latency and network failure. Fog computing faces main issues of security and devices authentication which are involved at different gateways. Fog computing brings the cloud closer to these devices to resolve and sort these challenges. They mainly focused on networking of IoT. Fog computing covers mobile networks, wireless networks, hardware and software. They cover the end users, network edge and over access networks. All architecture, enabling technologies and IoT applications are supported by 4G and 5G.
[60]	Mineraud, J., Mazhelis, O., Su, X	Evaluated application developers, device providers and end users on different parameters. They highlighted the shortcomings of present IoT solutions. They analyzed all these parameters, shortcomings and based on their analysis recommended solutions for improvement in future IoT ecosystems.
[61]	Sun, Y., Song, H., Jara, A.J. Bie, R	Highlighted how IoT integration with big data can enhance and boost the revitalization, attainability, preservation and livability of smart, intelligent and connected communities.
[62]	Dimitrov, D.V	Emphasised on the organizational, business and behavioural issues in IoT which are very important for self, society, organization and industry.
[63]	Ahuja, S, Johari R, Khokhar C	Described the different architectural design and applications of IoT for Health Care Management Information System.
[64]	Trupti Mayee Behera, Sushanta Kumar Mahopatra, Umesh Chandra Samal, Mohammad S. Khan	Proposed that wireless sensor networks sensors hin such a way that have limited battery and recharging and replacement of these batteries is not possible. Power consumption is very vital in energy conservation. Clustering algorithms are very useful and by selecting a cluster head balances the network load. They highlighted selection of cluster head on rotation basis which reduces consumption of energy. The algorithm selects the CH on basis of initial energy and residual energy. An optimum CH is selected suitable for IoT applications
[65]	A. Ali, Y.Ming, T. Si, S. Iram, S. Chakraborty	Proposed that major challenge in IoT is handling of massive number of sensors in terms of cost, servicing and maintenance. Replacement of batteries of sensors located in network field is not possible. Power management and energy conservation is another challenge in IoT. The sensors which are deployed on animals must have the battery which should last longer than the life of animal
[66]	H. Farman	Modified Leach protocol to improve performance of network. They proposed a non probabilistic Cluster Head selection scheme based on multiple criterion. They divided the network in different zones and the zonal head was selected by using analytical network process. Different parameters are defined and based on best parameters the ZH is finalized
[67]	T.M. Behera, U.C. Samal, S.K. Mohapatra	Proposed an improved energy efficient LEACH protocol for different IoT applications. The increase in population in urban areas requires suitable services to satisfy the users demand. They highlighted a single hop clustering protocol that saves massive energy in comparison of non clustering algorithms
[68]	Butler, D.	Proposed that when different devices are able to sense environment, gather data and communicate they are really useful. They become capable to analyze that data and take suitable action according to the decision taken on the basis of that data analysis. They are able to understand complexity and generate action swiftly. The (MIS) Management Information System is widely being deployed and work without any interference of human beings which is a great advancement and revolution. IoT means coding of different devices, their networking to enable them to sense, capable of being identifiable, become readable by machines and traceable on internet.
[69]	S. Zhang, G. Wang, T. Peng, K.-K. R. Choo, X. Mao,	Proposed that SMART (IIoT), Industrial Internet of Things includes smart manufacturing, smart factory, industrial property management, equipment monitoring and manpower deployment.

(*continued on next page*)

Table 2 (*continued*)

Ref.	Authors	Summary of works presented
		This is attracting increased attention from industry and is being used
[70]	B. Cao, G. Min X. Liu, Z. Lv, P. Yang, J. Zhao	Proposed that the devices and sensors deployed in industry generate massive data which has to be processed properly as there is limited storage capacity and computational ability
[71]	L. Hu, T. Wang, M. Xie, A. Liu	They proposed (SCS) sensor based cloud system. This integrates sensor nodes & cloud computing to manage and utilize the storage capacity, processing power and computational ability of the cloud. It process the massive data being generated in industrial IoT
[72]	V. A. Memos, B. Gupta B.-G. Kim, Y. Ishibashi, K. E. Psannis,	Proposed that (SSS) smart surveillance systems which are based on sensor based cloud system (SCS) will help the users in processing and analyzing the massive industrial data on demand
[73]	X. Liu, K. K. L. Wong, A. Liu, M. Zhao	Proposed that with the integration of cloud computing and current network new issues will be generated which needs to be addressed
[74]	T. Wang, A. Liu, L. Qiu, A. K. Sangaiah G. Xu	Proposed that the limited storage capacity and computation capability are the major limitations. Sensor nodes deployment and their vulnerability to environment make it difficult for them to gather quality and valid data. This in invalidity of data
[75]	L. Qi, X. Xu Q. He, S. Li, C. Hu, R. Wang,	Highlighted that increase in network connectivity can magnify the damage of malicious nodes. This may result in damage, disruption or loss of life
[76]	D. Gambetta	Proposed that trust management system can be considered in sensor based cloud system (SCS) enabled industrial Internet of Things (IIoT). Trust means faith, knowledge, certainty, ability, credence, goodwill and reliability of others. Trust management system is used in sensor based cloud system (SCS) for detecting the malicious nodes. It assures the normal working and operation of nodes. Present trust management systems are classified into two types, centralized and decentralized.
[77]	Z. Yang, V. C. Leung, K. Zheng, L. Lei, K. Yang	Highlighted that a trust management systems which is centralized is having a centralized server or computation centre which evaluates the sensor nodes trust value and stores centrally.
[78]	O. A. Wahab, A. Mourad, H. Otrok, J. Bentahar	Highlighted that the trust management systems which are centralized have high evaluation accuracy and simpler implementation in comparison with decentralized trust management systems. The disadvantage of trust management systems is that the computation centre and sensor nodes use multihop transmission for communication. This increases the consumption of energy of the network
[79]	G. Han, H.C. Chao, J. Niu, L. Shu, J. Jiang	Proposed that the trust value of a sensor node is evaluated and stored by the neighboring nodes in a trust management system which is decentralized. The trust evidence of sensor nodes is imitated and derivate from their behavior of communication such as rate of energy consumption and success rate of communication.
[80]	C. Zhang, G. Almpanidis X. Zhang C. Liu,	Proposed that the decentralized trust management systems are better than the centralized one in terms of energy consumption and response time. They have reduced consumption of energy and offers fast response time. Various trust evaluation algorithms are complex and are based on (AI) artificial intelligence. These complex algorithms are difficult to implement on sensor nodes because of limited storage capacity and computational capability. Increase in network scale and multihop trust transfer has resulted into hike in consumption of energy and distortion of trust value. Therefore trust management systems centralized as well as decentralized faces the problem of distortion in trust value and increase in energy consumption with the increase in network size. The limited storage capacity and computation ability of nodes makes it difficult to conduct trust evaluation mechanism. These issues and problems needs to be addressed.
[81]	G. Xu, A. K, Y. Zhang	Adopted edge computing and proposed mobile elements known as (MENs) mobile edge nodes. They have relatively strong computation power and storage capacity for conducting trust evaluation. They are used as bridges for connecting upper remote cloud center with lower networks.
[82]	T. Wang, M. Xie, X. Zheng, H. Luo	Highlighted that mobile edge nodes (MENs) mobility enables them to evaluate short range nodes. It reduces consumption of energy and improves trust evaluation accuracy. (MTES) mobile (edge based) trust evaluation scheme is proposed which adopts the probabilistic graphic representation for depicting the relationship which exists between the sensor nodes. It calculates the trust values of different nodes very accurately.
[83]	M. Liu	Proposed trust mining method for dealing with problems in large scale systems like sparse evaluation and cold start. For discovering the hidden trust relationship they proposed roundtable gossip algorithm. They also proposed an anti-sparsification method for overcoming the randomness of trust propagation. They also introduced MENs for overcoming trust propagation randomness.
[84]	A. Karati, M. Karuppiah, S. H. Islam	Proposed lightweight & secure signature scheme for authenticate data. They designed novel signature scheme which is certificate less. It deals with Type-I & II adversaries. They focused on data provider behaviors.
[85]	J. Jiang, M. Guizani, L. Shu, F. Wang, G. Han	Considered the trust issue in integration of cloud computing & IoT. They proposed novel method of crowd sourcing for recruiting the mobile elements for evaluating the underlying nodes trustworthiness. They used fuzzy logic method for calculating trust value of every node. They also focused on integration of MENs and underlying nodes. This improved SCS enabled industrial IoT performance.
[86]	Z. Zhang, X. Liu, Y. Xin, S. Luo, H. Zhu	Considered trust evaluation of cluster heads and sensor nodes in Industrial IoT which is cluster head. Cluster head gathers data from all neighboring nodes. It collects and stores data on the base station. Cluster head monitor communication behavior & data quality of neighboring sensor nodes. They proposed MENs instead of cluster for conducting trust evaluation.
[87]	M. H. Ling, Q. Ni, J. Qadir, K. A. Yau	Proposed artificial intelligence based model for addressing the trust issue. They proposed trust model based on reinforcement learning for adjusting the size of cluster in distributed cognitive radio networks
[88]	U. Jayasinghe, Q. Shi, T. Um, G. M. Lee	Proposed machine learning based model for trust computation in IoT services. They proposed probabilistic model for representing trust relationship in industrial environment
[89]	Y. Ren, F. Y. Li, V. A. Oleshchuk, V. I. Zadorozhny	Considered security of storage of trust value. They proposed trust storage method in industrial

Table 2 (*continued*)

Ref.	Authors	Summary of works presented
		IoT for preventing tampering of trust value of sensor nodes. They proposed three different schemes & verified them. They also proposed various methods for detecting trust pollution attack. They applied trust evaluation of industrial IoT from various perspectives. They focused in developing new trust evaluation methods. The issues and challenges of distortion in trust value and energy consumption remains unsolved. They proposed MENs to address and tackle these two problems.
[90]	N. Das, M. S. Obaidat B. E. Wolfinger, S. Misra	Proposed detailed MTES design. In smart surveillance systems the deployment of sensor nodes are done randomly. They monitored the industrial environment. They gathered data from sensor nodes and have spatial & temporal correlation. Relationship of sensor nodes is represented by using probabilistic graph model.
[91]	D. Koller, F. Bach N. Friedman	Proposed AI method probabilistic graph model. It consists of three parts reasoning, representation and learning. Representation of relationship between different entities depends on network structure in industrial IoT which is SCS enabled. Reasoning is correlation between different nodes and collection of data for inferring the trust value of nodes in evaluation of trust. Learning refers to parametric learning. MENs update parameters of node and relationship between nodes. MTES objective is detecting malicious nodes in network. They calculate trust value of node from data collection and their communication behavior. MENs make comparison between collected data & neighboring data. Trustworthiness is measured by sensor nodes behavior and behavior history.

(c) Presentation – comprises of interpretation and visualization tools that make things easier to understand and is helpful in designing of different applications.

3. Technology

Internet of Things is system of internet connected devices having unique identification. They are capable of collecting data from environment and transferring it through the network without any human intervention. There is a need of improved technology which can be achieved by integration of various enabling technologies with help of which the devices can be identified and made to communicate with one another. The technologies which contributed in development of IoT are discussed in this section as proposed by Y. Wu, J. Li, J. Stankovic, K. Whitehouse et al. [92]. IoT has advanced due to merging and concurrence of various enabling technologies like Big data, Cloud computing, artificial intelligence, machine learning, embedded systems, real time analytics, automation, control systems, wireless sensor networks and commodity sensors. With advent of IoT everyday things and devices like television, car, vehicles, refrigerators, general consumer products, health care equipments will become capable to sense and track. These devices contain advanced processing and networking capabilities which enables them to track and sense the environment. IoT relies on blend of hardware, software and architectures. IoT covers devices like home appliances, security systems, cameras, lighting fixtures, thermostats and others which supports common ecosystems. They are controlled through devices which are associated with that particular ecosystem, like smart speakers & smart phones.

3.1. Hardware

The IoT hardware already exists and is widely used like RFID, NFC and Sensor Networks as proposed by Dominikus et al. [93], Khoo et al. [94], Schmidt et al. [95], Welbourne et al. [96] and Sheng et al. [97].

3.1.1. (RFID) radio frequency identification

The idea of Auto-ID Center is originally based on RFID-tags and the distinct identification was made possible due to Electronic Product Code. This has resulted into devices or objects having IP address as proposed by Hassan et al. [98].

(RFID) Radio frequency identification makes use of electromagnetic fields for identifying & tracking the tags which are attached to various devices. These tags contain the data related to specifications of devices which is stored electronically. Active tags have local battery source and possess the capability of operating even hundreds of meters away from RFID reader. Passive tags take energy from radio waves of nearby RFID reader. RFID tags do not require being within the line of sight of reader. It can therefore embedded within tracked device. RFID is best technique for identifying & capturing data automatically. These tags are utilized in multiple applications. RFID tags fastened to a car during production are used for tracking its progress in assembly line. RFID tag connected pharmaceuticals are tracked through repository. RFID tagged animals & pets can be tracked, counted and identified. RFID tagged clothes in a showroom makes them secure from theft. RFID is short distance communication in which the RFID tagged device communicates amidst RFID reader through electromagnetic fields. Tags contain various types of data forms. (EPC) Electronic Product Code is the data form which is mostly used in IoT applications. It provides unique identity to every device ensuring that they can be individually tracked. This technology is widely used in retailing, logistics, supply chain management, food safety, public utilities, assembly lines, aviation & many other applications. Capabilities of identifying and tracking offered by RFID are very useful in Internet of Things applications. Low powered IoT devices can be powered with photovoltaic cells which serve as on board power sources. Sai Nithin R. Kantareddy, Ian Mathews, Shijing Sun, Mariya Layurova, Janak Thapa, Juan-Pablo Correa Baena, Rahul Bhattacharyya, Tonio Buonassisi, Sanjay E. Sarma and Ian Marius Peters et al. [99] proposed usage of perovskite solar cells for powering IoT devices based on backscatter Radio Frequency (RF). Perovskites solar cells are economical, offers flexible light energy harvesting, low temperature processing and higher performance. Perovskites extend range & lifetime of current backscatter techniques like Radio Frequency Identification (RFID). Perovskite are most suitable for future low power wireless applications. They realized powered wireless temperature sensor using perovskite cells with communication range of 4 m. They used a 10.1% efficient perovskite PV module which generated 4.3 V output voltage just requiring power of 10–45 μW range. Onboard energy harvester provides an extra energy for boosting the sensor range. Perovskite cells fulfill the energy requirements by enabling autonomous low power RF backscatter applications. They proposed self powered low cost IoT sensors & concluded that integrating RFID and perovskite photovoltaic's offers the synergies into wide range of applications.

Jiqiang Feng, Feipeng Li, Chen Xu, and Ray Y. Zhong et al. [100] proposed data driven analysis for RFID enabled smart factory. Internet of Things (IoT) and upcoming manufacturing factories resulted in massive data which increases complexity. Radio frequency identification (RFID) is key enabling IoT technology. It is used for collecting real time data during production for supporting the decision making of manufacturing in smart factories. These upcoming technologies have resulted in generation of massive data. Jiqiang Feng proposed big data approach for extracting useful information from this massive data. Quality and time are the main metrics. Processing times, failure rates, accuracy, percentages of parts, process types are calculated in smart factory. Production efficiency, are noted for every workers using User IDs & Process IDs. The key findings, analysis, and observations are used for making advanced decisions in smart factory. It makes full utilization of RFID captured data.

They were motivated by company which used RFID technology for ten years. Massive data was gathered from production shop floors. The workers, machines, manufacturing jobs, materials were associated. Quality of data captured and processing time were analyzed to investigate the performance of production in RFID enabled factory. Advantages of RFID are that the data can be accessed remotely via internet, size is reduced and is economical. It can be easily integrated in a device. It is a microchip transceiver like a sticker which can be active as well as passive. Active tags having attached battery makes them active always. Passive tags can be made active by triggering. RFID system comprise of tags and readers for identifying the device. They confirm the location and specifications of that device. When appropriate signal is generated they are triggered. These signals carrying data are transmitted to readers by using radio frequencies. They are then given to processors for analyzing the data produced as proposed by W. Xu, W. Trappe, Y. Zhang et al. [101].

Radio spectrum is part of electromagnetic spectrum with frequency ranging from 30 Hz to 300 GHz. Electromagnetic waves operating in this frequency range are called radio waves. They are widely used in applications related to telecommunication. RFID systems function in four ranges of frequency LF, HF, UHF and microwave. All these ranges are part of frequency bands named as Industrial, Scientific and Medical bands. The tags are created to function in any of these ranges. The main factors for selecting the frequency range are read range and device material which is required to be tagged. Radio waves perform differently at different frequencies. Each is having its own merits and demerits. RFID system operating at lower frequency has slower data read rate. The capability to read near liquid and metal surfaces increases. RFID system operating at higher frequency has speedy data rates of transfer. They have extended read ranges. They are more sensitive to radio wave interference which is due to the metals and liquids present in environment. Recent advancements have resulted in use of ultra high frequency around metals and liquids

3.1.1.1. Low frequency range (less than 135 kHz). The Low frequency range is 30–300 kHz. LF RFID systems function at 125 kHz and 134 kHz. It gives shorter read range of around 10 cm. It is having slower read speed as compared to higher frequencies. It is not sensitive to radio wave interference. Its applications are access control, animal & livestock tracking.

3.1.1.2. High frequency range (up to 13.56 MHz). The High frequency range is 3–30 MHz. HF RFID systems work at 13.56 MHz. It provides read range from 10 cm–1 m. It's moderately sensitive to the radio wave interference. Its applications are data transfer, payment, tracking and ticketing. Near Field Communication is short range technique for exchanging data between nearby devices. It is used in proximity cards and credit cards.

3.1.1.3. Ultra high frequency range (862–928 MHz). The Ultra High frequency range is from 300 MHz to 3 GHz. This band provides read range up to 12 m. It has a faster data transfer rate in comparison of LF and HF. It is very sensitive to the radio wave interference. UHF product manufacturers have found different ways for designing RF tags, antennas and readers for superior performance. Passive UHF tags are economical and are simpler in comparison of LF and HF tags.

3.1.1.4. Microwave frequency range (2.4–5.80 GHz). RAIN RFID systems use frequency range from 860 MHz to 960 MHz. In some countries it functions from 900 MHz to 915 MHz. Its applications are pharmaceutical anti counterfeiting, wireless device configuration, retail and inventory management. RFID projects are now using RAIN making it the fastest growing segment of RFID market. The detailed comparison is presented in Table 3.

3.1.2. Internet protocol

Internet Protocol is a principal protocol widely used for communication. It is used for transmission and relay of datagram's across the network. The different versions are IPv6 and IPv4 which defines IP address differently. IPv6 is new 21st century Protocol. It provides availability and addresses 85,000 trillion whereas IPv4 addresses 4.3 billion as proposed by Bicknell et al. [109].

3.1.3. Electronic product code

Electronic Product Code developed in 1999 for the first time at MIT by Auto ID centre. It is a code of 64 or 98 bit electronically stored in RFID tag. EPC code is utilized for storing the full information related to specification of the product like unique identification, product serial number, complete technical and commercial specifications of the product, information of manufacturer, year of manufacture and the EPC type. EPC comprises of EPC Discovery Service, Object Naming Service, Information and Security Services. (EPC Global, 2010) EPC global organization is in charge for the development of EPC and accountable for maintaining its uniformity and standard. They constituted EPC global network for distribution of the RFID related information.

3.1.4. Barcode

Bar Code is similar to RFID used as identification technology. Barcode is a distinct method of representing the data in machine readable visual form. Barcodes represent data by variation in spacings & width of parallel lines. Letters and numbers can be encoded by use of different combinations of spaces & bars of variable width. These are (1D) one dimensional or linear. They can be scanned using barcode readers and optical sensors. Bar Codes are labels sticked to the products which are optical and machine readable. They are used for recording and storing specification related to that product.

Roger C. Palmer et al. [111] in its Bar Code Book highlighted that for data entry there are other methods and techniques also. (QR) Quick Response codes are (2D) two dimensional also known as matrix codes. They were created for Japan's automotive industry. QR Codes are very popular in automotive industry because of its large storage capacity and fast readability. Barcodes are of three type's numeric, alpha numeric and two dimensional. Barcodes are machine readable and can be scanned by a scanner or can be read by using cameras.

RFID is better than Barcode due to several benefits. RFID do not need line of sight. The reader need not be in vision physically as it uses radio waves. However Barcode require line of sight. It is an

Please cite this article as: P. Goyal, A. K. Sahoo and T. K. Sharma, Internet of things: Architecture and enabling technologies, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.678

Table 3
Work Highlighted in Area of RFID.

Ref	Author	Highlighted Area
[102]	ITU	Highlighted that IoT was originally inspired by RFID community members. They highlighted that the information regarding a tagged object can be obtained by browsing internet by an address or by browsing the data base finding an entry corresponding to that particular RFID.
[103]	Graham, M. Haarstad, H	Proposed that IoT contents are created via RFID tags & IP addresses which are linked through (Electronic Product Code) EPC network
[104]	Li, Yu, J.J, B.A.	Proposed that the main IoT technologies are RFID, smart intelligent embedded technology, sensor technology and nano technology. The basic foundation stone among all these technologies is RFID and is the core technology responsible for the growth of IoT
[105]	Sun, C	Highlighted that RFID makes use of radio waves for identifying and tracking the tags which are attached to different devices. They transmit the identity of device as a serial number through wireless using electromagnetic fields.
[106]	Moeinfar, D Nafar, F Shamsi, H	Proposed that main component of RFID is RFID tag which consists of a microchip attached to antenna, a reader which consists of scanner with antennas, a processor or controller for receiving the input from reader and for processing the data. RFID is reliable, secure, efficient, accurate and economical. It has broad range of applications like tracing, tracking, distribution, supply chain, logistics, health care, patient monitoring and military.
[107]	Jia, X., Lei, Q Fan, T. Feng, Q.,	Described that RFID through different radio waves identify the devices, collect and analyze the data and control the devices individually. They analyzed that RFID Reader is responsible for reading, identifying, tracking and monitoring of devices connected through internet. Tagged devices are automatically detected in real time. RFID is a foundation technology responsible for the growth of IoT. They proposed different aspects, specifications, roles, architecture, network, applications of RFID & IoT. They also discussed the role of supporting and enabling technologies of IoT.
[108]	Aggarwal, R. Lal Das, M	Highlighted that IoT is best described as global network connecting different devices, each of which is having a unique identity. These communicate with one another, device to device without involvement of human being. They can also communicate between human to devices and devices to human. For the first time RFID was used in Britain in 1948 in second World War. It was utilized for identifying the enemies. Later on RFID was used in Auto ID center in 1999 at MIT. RFID identify the devices, objects and things around us very economically and plays a major role in success of IoT. RFID is Active, Passive and Semi Passive according to power supply provisioning in tags.

optical technology so need the reader to be physically in vision otherwise it will not work. RFID can trigger the various events as it can also work as an actuator. It has the adaptation abilities which Barcodes do not have as proposed by W. Zeiler, R. Houten, G. Boxem et al. [112] and Fleisch, E., Mattern F and Das et al. [113].

3.1.5. Wireless fidelity (Wi-Fi)

Wi-Fi is used for networking of devices through internet. It allows the devices and computer to communicate via wireless signal. It was first introduced by Vic Hayes et al. [114]. He was Senior Research Fellow at the Delft University of Technology. His work in area of Wireless Local Area Networks has made him renowned as Father of Wi-Fi. Wi Fi was invented in 1991 at Nieuwege, Netherland by NCR Corporation. First wireless product launched in market was Wave Lan which was having a speed of 1 Mbps to 2 Mbps. Presently it can achieve speed of 1 Gbps. Wi-Fi generally use 2.4 GHz and 5 GHz radio bands. Wi-Fi is widely used and delivers high speed network connectivity. It is adopted by various offices, buildings, homes, institutes, universities, hotels, resorts, restaurants, cafes and public locations such as Railway Station, Bus Stand and Airport. Entire Smart City can now be connected to Wi-Fi via wireless APs. The adoption of Wi-Fi has increased tremendously due to integration of Wi-Fi in laptop, computer, tablets, mobile phones and consumer electronic devices as proposed by Pahlavan, K., Krishnamurthy, P., Hatami, A., Ylianttila, M., Makela, J.P., Pichna, R. Vallstron, J. et al. [115].

3.1.6. Bluetooth

Bluetooth is used for data exchange between computer and devices at small distance using low wavelength ultra high frequency *radio waves*. It is *wireless* technology standard which utilize *radio waves* in scientific medical and *industrial* radio bands. It is an alternative to the *RS-232* cables. It is economical and has eliminated the requirement of a wired connection between handheld devices such as Computer, Laptop, Cameras, Printers, Mouse, Gaming Devices and Xerox Machine up to range of 100 m. Bluetooth project was first launched in the year 1994 by Ericsson, a mobile communication company. It is used for creating (PAN) Personal Area Networks. The *IEEE* has standardized it as 802.15.1. Piconet is a cluster (two or more than two) of Bluetooth devices which share a common synchronous communication channel. It is an Adhoc network linking devices using bluetooth protocols for sharing data such as text, images, audio and video. Bluetooth is governed by (SIG) *Special Interest Group*. It is having around 35,000 companies as members working in field of telecommunication, computing, consumer electronics and networking. SIG supervise and manage improvement of specification, protects the different trademarks and looks after the qualification program.

3.1.7. ZigBee

Zigbee is high level communication protocol utilized in creating personal area networks. It use low data rate, low power, close proximity and small digital radios. It is 802.15.4 IEEE standard. It was developed by ZigBee Alliance in 2001. It has bandwidth of 250 kbps. It supports 10–100 m line of sight physical range. It is widely used in applications related to IoT, medical, scientific and industrial. It is specifically designed for projects which require wireless connection. It was developed for improving wireless sensor network features. It is simpler, economical and consumes less power in comparison with Bluetooth & Wi-Fi. It is most suitable in short range with low rate of data and low power. It is flexible, scalable and a reliable protocol. Zigbee devices are capable for transmitting data at far places by sending it via mesh network comprising of transitional intermediary devices. It supports tree, mesh and star topologies. It is broadly used in smart homes, healthcare, patient monitoring [110], industrial automation, control, agriculture, medical and power systems. Applications include wireless home energy meters, light switches, consumer equipments, traffic management and industrial equipments that require short range low data rate wireless transfer as proposed by Chen, X. Y. Jin, Z. G. et al. [116].

3.1.8. Near Field Communication

NFC comprises of set of communication protocols which enables different devices to communicate when they are near in close proximity range of around 4 cm. It was created by Sony and Philips companies. It uses a 13.56 MHz base frequency. It uses a simple setup and offers low speed connection which is used for bootstrapping much capable wireless connection. It do not require line of sight to communicate. NFC tags have a unique code for identification. NFC technology is embedded in smart phones enabling them to transfer data to each other. NFC devices can detect and

Please cite this article as: P. Goyal, A. K. Sahoo and T. K. Sharma, Internet of things: Architecture and enabling technologies, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.678

connect with NFC tags which are passive. They are unpowered but connected to devices. NFC technology is very useful in day today life as it becomes simple to transfer money, exchange digital data and information. It is easier for the consumers to connect devices and make transactions by a simple touch. Smart posters use NFC tags which are readable. The data can be easily read through these posters containing NFC tags and transferred to smart phone. NFC is used for sharing contacts, photos, images audio and video files for social networking. NFC devices are used in contactless payment systems, electronic ticket smart cards and credit cards. They enable mobile payment system to replace these systems. This is referred to as contactless CTLS NFC. NFC enabled devices are also used as keycards and electronic identity documents.

3.1.9. Actuators

An actuator is a mover. It is a component or part of a machine which can control and move a mechanism or system. The actuator requires control signal and a energy source. Control signal can be in the form of electric current, electric voltage, pneumatic pressure, hydraulic, human energy or power. The control system can be electronic system, mechanical, robot control, human, software based. Actuator is actually a mechanism where control system acts upon status from an environment given by sensors. When actuator receives control signal it converts energy of control signal into mechanical motion. It uses hydraulic fluid, electric current, compressed air or other power sources. It is capable of creating an oscillatory rotary or linear motion. It is capable of covering 30 feet distance and communicates at less than 1 Mbps. It is used in manufacturing and commercial applications

Types of Actuators:

(1) Electrical: use electric current to actuate motion for example stepper motors, dc, ac motors and solenoids
(2) Hydraulic: use hydraulic fluid for actuating the motion suitable for applications which require high force for example engineering vehicles, manufacturing machines and hydraulic drive systems
(3) Pneumatic: use compressed air for actuating the motion for example rotary actuators, vacuum generators and vane motors.

Electric actuators are mostly used. Pneumatic and hydraulic systems are capable of providing elevated torque and force. They are used in industry and manufacturing companies.

3.1.10. Wireless sensor networks

Wireless sensor networks are cluster of partially dispersed, dedicated sensors placed at equal distance for monitoring the environment. These sensors are used for gathering, recording and collecting the data in a centralized server. WSNs measure the environmental conditions such as sound, light, speed, motion, humidity, temperature, pressure, vibration, quantity, pollution etc. WSNs are like wireless ad hoc networks as they rely on wireless connectivity and instant formation of networks so that the data of sensor can be transmitted wirelessly. WSNs comprise of spatially distributed sensors which automatically monitor the environmental and physical conditions. They gather the data and pass it to the central point. WSNs are bidirectional and enable control of the activities of sensor. WSNs came into existence due to requirements in military applications and are now widely deployed in home automation, consumer products, industrial applications, supply chain logistics, healthcare, agriculture for monitoring and control. Nodes are the basic building blocks of WSNs. These nodes may vary in numbers from few nodes to several thousands. Each and every node is connected to various sensors. Node consists of a radio transceiver, antenna, microcontroller, electronic circuit & an energy source. Node varies in size and motes are of microscopic dimensions. The cost of nodes also varies and depends on its complexity. Nodes cost and size results in several resource constraints like energy, computational speed, memory and communication bandwidth. WSNs topology varies from simple star to advanced multihop wireless mesh network. Routing or flooding propagation techniques are used between network hops. Each node acts like a transceiver having a communication, actuation, sensing unit, storage unit and a power source for example antenna, microcontroller, interfacing circuit, memory and battery as proposed by Floerkemeier, C., Mattern, F et al. [117], Floerkemeier, C., Langheinrich, M., Fleisch, E., Mattern, F., Sarma, S.E. et al. [118] and Frank, C., Bolliger, P., Mattern, F., Kellerer, W. et al. [119].

Sensors are responsible for sensing the data from environment. Actuators are responsible for performing the actions to affect the state of object or environment. Actuators and sensors are clubbed to make sensor actuator networks. They are used in military and commercial applications. IoT devices are capable of communicating and interacting with one another and also with humans. In fire alarms in a building, sensors are used for detecting the carbon mono oxide present in a room and the actuators are used for generating a loud sound as alarm for alerting the people in case of fire and detection of harmful gases. Sensors and actuators are used in combination to enable the objects to be vigilant of the state and environment and take action accordingly by interacting with each other. Integration of WSN and IoT find applications in various areas like Smart Home, Smart City, Security, Healthcare, Agriculture, Industry, Manufacturer, Fire detection, Flood detection and Military etc. as proposed by Arampatzis, T. et al. [120].

3.1.11. Cloud computing

Cloud computing is availability of storage facility on demand along with power of computing. It is the use of computer resources without any direct involvement of the user. It is used to describe the availability of data centers to multiple users connected through Internet. Large clouds have functions which are distributed over multiple locations from the central servers. If the connection is very close to the user it is known as edge server. Clouds can be private which are dedicated for a single organization also known as enterprise cloud. Clouds can be public which are available for multiple organizations known as Public cloud. Cloud computing is dependent on effective resource sharing for achieving economy, continuity and consistency. Cloud computing is very beneficial to companies for minimizing IT infrastructure costs. It also helps them to get their applications up and run faster. It improves manageability and requires less maintenance. It is also helpful in effective resource allocation and adjustment to meet the unpredictable and fluctuating user demands. Cloud Computing is growing exponentially due to availability of computers, storage devices, hardware virtualization, service oriented architecture, high capacity networks use of virtual techniques and automatic utility computing. Cloud computing is capable of storing and analyzing huge data. Internet connected devices are continuously increasing. They have crossed 26 billion at present and are expected to cross 75 billion by 2025. Servers being converged to single cloud platform allow resource sharing which can be accessed from anywhere, anytime. This is a valuable and useful feature used in IoT which provides high capacity of storage, increased power of processing, helps in analyzing the data collected from sensors. Cloud computing integrated with smart things or devices using various sensors is very helpful and beneficial for IoT as proposed by Hui, J., Culler, D. et al. [121].

Please cite this article as: P. Goyal, A. K. Sahoo and T. K. Sharma, Internet of things: Architecture and enabling technologies, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.678

3.1.12. Networking technologies

Computer network is a telecommunication network over which the nodes share resources. In computer networks, the devices interact with each other using data links between the connected nodes. This connection or data link is established through wired media such as cable, twisted pair, fiber optic cable and wireless media like Wi-Fi, Bluetooth. Network nodes are those which are responsible for originating, routing and terminating the data. Nodes are identified by their network addresses. They include hosts such as smart phone, personal computers, servers and networking hardware like switches and routers. When one device is capable of interacting and exchanging data and information with other devices then they are networked, whether they have a direct connection or not. This collection of information technology requires proficient, reliable and adaptable network to keep it running. Computer networks provide support to services and applications like digital audio, digital video, messenger, mail, servers, World Wide Web access, shared resources like printer, fax machine and storage devices. Computer networks can be differentiated on the basis of topology, size of network, communications protocols, transmission medium, network traffic and traffic control mechanism. Internet is the best computer network and is called network of networks. These networking technologies are driving growth and development of IoT. A fast, reliable and effective network is required for handling the huge data generated by large number of devices. We use 4G for wide range network but the mobile traffic is unpredictable so now we are moving to 5G. We use Bluetooth, Wi-Fi for short range network as proposed by International Telecommunication Union ITU et al. [122]. Wireless Communication, higher rates of data transfer with high speed continuous connectivity is users demand. IoT in 5G is a revolution and provides low latency, low interference, increased data rate, connectivity with multiple devices and increased bandwidth as proposed by Parul Goyal, Ashok Kumar Sahoo et al. [123].

3.1.13. Nano technologies

Nanotechnology is manipulating and manufacturing of materials and devices matter on atomic, molecular and super molecular dimension scale. Nano technologies refer to the wide range of applications where primary focus is size. The associated research is equally diverse which ranges from device physics to molecular physics. Nanotechnology will result in creation of new devices and materials with variety of applications like nano electronics, nano medicine, biomaterials, commercial and consumer products. Nanotechnology is also being used in industrial and purification processes like water desalination, water filtration, groundwater treatment, waste water treatment and other nano remediation. Industrial applications include nano machining of nano wires, nano-rods, construction materials and military goods. Nanotechnology realizes improved and smaller version of the interconnected things. Nanotechnology results in development of devices in nano meters scale. These nano sensors and actuators work like normal size sensors and actuators. Their usage reduces power consumption. Nano devices are made from nano components. The resulting network is popularly known as (IoNT) Internet of Nano Things as proposed by Kindberg, T. et al. [124].

3.1.14. Micro electro mechanical systems (MEMS) technologies

MEMS are technology of microscopic devices with movable parts. It is known as nano electro mechanical systems (NEMS) at nano scale. In Japan MEMS are known as micro machines and in Europe they are called micro systems technology. They are made of components varying in size from 1 and 100 μm. MEMS devices size ranges from 20 μm to a millimeter. MEMS comprises of a central unit such as microcontroller which is used for processing of data. It has components such as micro sensors that interact with the surroundings. Forces generated from ambient electromagnetism like magnetic moments, electrostatic charges, fluid dynamics like viscosity and surface tension are very crucial design considerations. When the MEMS could be fabricated using semiconductor device fabrication techniques, it became practical to use. These device fabrication techniques include plating, molding, dry-wet etching and electro discharge machining. MEMS are mechanical and electrical components like actuators and sensors which work in combination to provide multiple applications. MEMS integrated with Nano Technology offers improvement in IoT as proposed by Kollmann, K. Das et al. [125].

3.1.15. Optical technologies

Optics is the branch of physics that describes light properties and behavior. Light is an electromagnetic wave generally infrared, ultraviolet, and visible. Other forms are microwaves, radio waves and X rays which have the same properties. A way of communication which uses signals encoded in light to transfer data and information in different types of networks is called optical networking. It includes local, wide, metropolitan, regional, national, international and transoceanic networks.

It is a form of optical communication that depends on lasers, optical amplifiers, light emitting diodes and wave division multiplexing. It is used for transmitting huge amount of data across fiber optic cables. It offers extremely high bandwidth so it is an enabling technology for high speed Internet and telecommunication networks which transmit data and information of majority of humans and machine. Optical communication is used in long distance communication using light to transmit data and information. It comprises of transmitter, receiver and a medium or channel for data transfer. Transmitter converts the original message signal to an encoded optical signal. The medium or channel carries the encoded optical signal to the receiver. Receiver decodes the received signal and reproduces the original signal.

Li-Fi and Bi-Di are the result of advances in optical technology. This is a major contribution in IoT growth and development. Li-Fi or light fidelity uses light for transmitting data at a very high speed through infrared, ultraviolet, visible light spectrums. LED lamps are used for visible light transmission. The technology is same as Wi-Fi as it use radio frequency for transmitting data. Li-Fi offers various advantages such as wider bandwidth channel, reduced electromagnetic interference and gives enhanced transmission speeds. Consolidation of data centers, emerging applications and server virtualization has resulted in need of higher data rates.

Cisco Quad 40 Gbps Pluggable bidirectional (BiDi) transceiver with Small Form Factor reduces the installation time. This results in reduction of overall costs. Customers migrated to connections of 40 Gbps data center links. The fiber infrastructure of 10 Gbps was reutilized for connections of 40 Gbps. Bidirectional technologies for big data generated from various IoT devices provides 40 Gbps Ethernet as proposed by Rafiullah Khan et al. [126].

3.1.16. Artificial intelligence (AI)

Artificial or machine intelligence is an intelligence which is exhibited by the machines. Any device that observes, sense the environment and accordingly initiate action for maximizing the chances of successfully accomplishing its objectives. AI describes the machines which imitate those cognitive functions which are closely associated with brain like problem solving and learning. Machine capabilities classified as Artificial intelligence include understanding of human speech, competing in strategic games like chess, automatic driverless cars, intelligent routing, home automation, smart healthcare, military simulations. AI attribute to sensitive & responsive environments. In Intelligent and smart world the connected devices helps the people in doing their day today

Please cite this article as: P. Goyal, A. K. Sahoo and T. K. Sharma, Internet of things: Architecture and enabling technologies, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.678

work in an easier and efficient manner utilizing data and intelligence of networked devices.

It is mainly characterized as

(1) Embedded: Embedded system is a controller for dedicated function embedded inside a larger electrical and mechanical system. It is embedded as part of a complete device including optimized hardware parts, software and real time operating system. Embedded systems control many devices in use.
(2) Context Aware: They are capable to collect and gather data from environment, analyze data, adapt behavior and guide responses. They recognize the situational context
(3) Personalized: They are tailor made as per user needs
(4) Adaptive: They are adaptive and responsive to the changes
(5) Anticipatory: They anticipate the things to come

3.1.17. Machine learning (ML)

Machine Learning provides the machine ability of learning and improving from experience. It focuses on development of machine programs that can access data and use it in its own learning. It is a scientific study and analysis of algorithms, analytical, statistical data models which machine uses for performing a particular assignment without use of explicit instructions. They rely on inferences and patterns. ML algorithms make a mathematical model which is based on sampled data called training data. This training data trains the machine and improves its learning experience. It helps in making advance predictions and decisions without any special programming for effectively and efficiently performing the task. Machine learning algorithms are useful in various applications where developing a normal accustomed algorithm is difficult and not feasible for efficiently and effectively performing the assignment. ML is related to computational statistics focusing on analyzing data for taking decisions and making advance predictions. Mathematical optimization techniques help in delivering models, methods, theory and application domains. ML also attributes as predictive analytics for the applications which are related to business problems. This is key enabling technology for IoT applications as proposed by Parul Goyal, Ashok Kumar Sahoo et al. [127].

3.1.18. Big data

It is a computational technology utilized for analyzing massive diverse data sets gathered. It deals with data sets which are complex and very large. It is used for systematically extracting information from that data. It reveals trends, patterns and associations related to human interaction. It is used for handling the data which are complex and too large. It cannot be handled by conventional data processing application software's. Major challenges of big data include data gathering, storage and analysis. Other challenges are data searching, sharing, transferring, updating, querying, visualization, data source, information security and privacy.

Big data utilize data analytics, behavior analytics & advanced predictive analytics for extracting values from the data sets. Data sets analysis is very useful in various applications such as business trending, preventing diseases, fighting crime. Data sets grow exponentially as they are gathered by various IoT enabled devices like smart phone, security cameras, RFID readers, remote sensing aerials, microphones, software logs and data, information sensing wireless sensor networks. Big Data statistics says that every person will be generating 1.7 megabytes per second data by 2020. There will be around 44 zettabytes of data by 2020. It's also estimated that there will be around 463 exabytes of data by 2025. Big Data is very useful in IoT based business optimization. A.W. Yusuf Asaju, Z.M. Dahalin, A. Ta'a, et al. [128] proposed improved framework for improving gain, reduce propagation loss by modeling mobile network. It enhanced quality of experience by using big data analytics

3.2. Software

Software is a collection of computer instructions which instructs the computer to work for an assigned task. Hardware is those parts from which the system is made and actually performs the work for an assigned task. Software is all the *information* which is processed by computer programs and data. Software includes computer programs, related data, libraries, online documentation and digital media. There is a requirement for improved software for supporting inter-operability between various kinds of heterogeneous devices. It search and gather data generated from different IoT enabled devices as proposed by Broll et al. [129] and Garrido et al. [130].

3.2.1. Middleware

Middleware is software which lies amidst applications and operating system. It serves as a bridge in between database, applications & operating system. It provides services to the applications beyond those which are offered by operating system. It helps software developers for implementing the communication input and output for focusing primarily on objective of their applications.

Middleware includes application servers, web servers, content management systems and analogous related tools which supports development of application and delivery. Services which are regarded as middleware are data integration, message oriented middleware, enterprise application integration, enterprise service bus and object request brokers. Developers use middleware for fulfilling the challenges which are associated with the wireless sensor network. Implementation of middleware application allows the wireless sensor network developers for integrating the various applications with hardware and operating systems. RFID software toolkit supports middleware for filtering redundant & noisy data. IoT includes various heterogeneous devices which generates huge amount of data.

IoT middleware exists in between hardware & software utilized in data applications created by developers. It helps to bring together various devices for enabling the developers for creating and deploying IoT services. This is implemented without writing different codes for multiple devices and various data formats. Researchers proposed usage of semantic middleware utilized for interoperating various types of devices which communicate using various types of communication formats. Semantic interoperability is computers ability of exchanging data. It is a need for enabling computable logic, data federation, knowledge discovery, inference & synchronism between various information systems as proposed by Hong et al. [131], Tozlu et al. [132], Zhu et al. [133] and Li et al. [134].

It is concerned with simultaneous transmission of data (syntax) meaning along with data (semantics). This is achieved by adding data information along with data (metadata). Meaning of data is also transmitted along with data. Semantic middleware creates a framework which allows sharing of data across various distributed devices, locations & applications as proposed by Aberer et al. [135], Gomez Goiri and Lopez de Ipina et al. [136], Huang and Li et al. [137] and Song et al. [138].

3.2.2. Browsing and searching

Browsing or searching is a type of orienting strategy. It identifies something appropriate for the browsing organism. The term browsing is used where students browse books kept in library. They browse database or surf the Internet. In library & information sciences browsing plays a very important role. It aims in design of suitable interfaces which helps the user in browsing. Search engines and browsers are designed for displaying and indexing stable web contents. IoT enabled devices are dynamic, mobile and generates huge amount of periodically changing data and information. There is a need for an IoT browser which has the capability of identifying smart things or devices. It must have the ability to interact with such devices by discovering them and identifying their services as proposed by Garcia Macias et al. [139]. Search engines must be capable enough to search the frequently changing data and gather data and information which is produced by the IoT devices as proposed by Ostermaier et al. [140].

3.3. Architecture

The devices connected to internet are increasing exponentially so massive data is produced which will not be handled by the existing infrastructure and architecture. This results in need of an open architecture which addresses quality of service. It must be capable of supporting existing network applications by use of open protocols. IoT is not adopted by all due to privacy and security issues which needs to be resolved.

Data Security & Privacy are major issues in IoT. Researchers have proposed various multi layer security architectures. IoT architectures are three levels, four levels, five levels and six levels. Five layer architectures incorporate the top features of both architectures. Architectures of communication networks and internet are based on TMN models & TCP/IP respectively. Six layer architectures is based on network hierarchical structure. In six layer architecture the coding layer provides identification to IoT enabled devices. In this layer, every device is entrusted a unique identification so that it becomes easier for differentiating these devices.

In IoT perception layer provides a physical meaning to each device. It comprises of IR sensors, RFID tags and other networks which have the ability to sense humidity, temperature, location and speed of devices. This layer collects and gathers data from devices through sensors. It converts collected data into useful informative digital signals. These signals are given to network layer for further processing.

Network layer

The Network layer receives digital signals carrying useful information from perception layer. It sends this information received to processing systems for processing and analysis. It uses various mediums of transmission such as Bluetooth, GSM, WiFi, Zigbee, WiMaX, 4G and 5G. It uses protocols such as MQTT, DDS, IPv4 and IPv6.

Middleware layer

This layer process data received from sensors. It utilizes cloud computing allowing access to its database directly for storage of necessary data. Data collected is processed and analyzed using smart processors and algorithms. An automatic action is initiated based on processed results and analysis.

Application layer

Application layer realizes different IoT applications based on processed data and information. Application layer is useful in IoT networks development. IoT based applications are smart wearable devices, healthcare, patient monitoring, homes, vehicles, agriculture, weather forecasting and smart city.

Business layer

Business Layer manages IoT services and applications. It develops various business models based on multiple strategies. It is also responsible for researches which are related with IoT. IoT along with combination of different technology helps in bridging the gap which exists between virtual & real world. The capabilities are:

Communication: Devices have the capability to connect, communicate and cooperate with one another through Internet. They are capable of making usage of data collected and accordingly update their status and state. Technology like UMTS, GSM, Bluetooth, Wi-Fi and ZigBee were used. Many others technologies are under deployment and development.

Addressability: Devices have the ability to be located and addressed via look up table. They are addressable via name and discovery services. They are remotely addressed, configured & controlled.

Identification: Devices have the ability to be identified uniquely. Even passive devices not having inbuilt energy resources are capable of being identified. The example is Near Field Communication, Radio Frequency Identification & bar codes which are optically readable. Identification enables devices to link to the data which is associated with that device. This information is fetched from the server via network.

Sensing: Devices gather data from their surroundings by sensors. They gather that data and information, forward it, store it, analyze it and act on it.

Actuation: Actuators in devices converts electrical signals to mechanical motion. Actuators are used for remotely controlling the devices through Internet.

Embedded information processing: Smart devices are those which have resources like processor, efficient algorithms and a storage capacity for processing data collected from sensors. The data is analyzed to extract interpret meaningful information. Adequate action is taken on the basis of analysis.

Localization: It helps to gather data and transmit it to the target position. Smart devices are apprehensive of their current location. Global positioning system and mobile networks are examples. Localization is very important in applications like ultrasound time measurements, radio beacons, wireless local area network base stations, radio frequency identification readers having known coordinates.

User interfaces: User interface in for computer human interaction. Smart devices communicate with people directly or indirectly as suitable for example smart phone. User interfaces are required for displays, voice, gesture and image recognition methods. To implement all the capabilities in one application is very expensive and complex requiring tremendous technical efforts. For specific tailor made applications only the required minimal capabilities are utilized. All the capabilities are not put in one application. Logistics applications are based on localization techniques which are approximate such as last read position. RFID & bar codes are very economical techniques for identifying the devices. RFID is very useful in day today activities like in hotel rooms the doors are opened with the help of smart key cards using short range communication. Smart card table used for playing cards can sense and monitor all the course of play by using RFID play cards. It can gather all data and store it. All such applications for local deployment involve scalable, dedicated, standardized and open systems as proposed by Wood, L. J. Stankovic, Fang and T. He et al. [141].

Architectures are required for representing, organizing and structuring IoT so as to function very efficiently. IoT heterogeneous requirements need such applications which are capable for supporting the hardware, software, network, process architecture, work flow, services and applications. Various architectures are proposed to provide support to the heterogeneous and distributed requirements of IoT. The various types of architectures include peer to peer architecture as proposed by Andreini et al. [142]. EPC global as proposed by Yun and Yuxin et al. [143]. Autonomic as proposed by Pujolle et al. [144]. Various architectures used for supporting IoT highlight the importance of standardization as proposed by Koshizuka and Sakamura et al. [145], Evdokimov et al. [146], Han et al. [147], Ning et al. [148], Quack et al. [149], Silverajan and Harju et al. [150], Uckelmann et al. [151], Zhang et al. [152], Zorzi et al. [153], Zouganeli and Svinnset et al. [154]

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Software architecture

They are essential for providing service sharing which are offered by IoT enabled devices. Service oriented architectures are proposed by Gronbaek et al.[155], James et al. [156] and Spiess et al. [157]. (REST) representational state transfer model are flexible and focused on services as proposed by Castellani et al. [158], Guinard et al. [159], Michael and Darianian et al. [160] and Wang et al. [161].

Process architecture: They are very important for effective structuring of business processes which will be incorporated using IoT. IoT is affecting and accelerating the business processes. Researchers have worked on how to structure the workflows to support the pervasive computing environments as proposed by Giner et al. [162] and Kawsar et al. [163].

General requirements

There is no particular or general architecture for IoT which suits all the applications. Researchers have proposed different types of architecture designs. Some researchers have developed the criteria for assessment of these architectures as proposed by Framling and Nyman et al. [164]. Some researchers have proposed the conceptual architecture for fulfilling the need and requirements of smart objects and devices as proposed by Kortuem et al. [165]. Researchers, authors and practitioners have proposed various models or architectures for IoT like Ning and Wang et al. [166], and Xiaocong and Jidong et al. [167]

3.3.1. European FP7 research project

This is basis for design of IoT architecture. (ARM) Architectural Reference Model was proposed by European FP7 Research Project. IoT-A is proposed from application based requirements, business considerations & present technology.

3.3.2. ITU architecture

This is proposed and recommended by (ITU) International Telecommunication Union. According to them, IoT architecture comprises of Application Layer, Middleware Layer, Network Layer, Access Layer and Sensing Layer. These are similar to (OSI) model Open Systems Interconnection in data communication & computer network.

3.3.3. IoT forum architecture

They proposed that IoT architecture consists of three types Processors, Applications & Transportation.

3.3.4. Qian Xiaocong, Zhang Jidong architecture

They proposed that IoT architecture is composed of Perception layer, Transportation layer and Application layer (Three Layered Architecture).

Perception layer collects and gathers data from devices. Transportation layer is responsible for transportation by providing network such as fixed telephone networks, OFC, mobile phone networks, data networks and broadcasting networks for carrier.

Application layer run various types of applications such as remote nursing, safety, defense, smart home, healthcare, patient monitoring, smart vehicles, smart traffic, smart agriculture, logistics & smart industries.

3.3.5. Kun Han, Dacheng Zhang, Shurong Liu & Ying Han's architecture

They highlighted that research were going on for SSME development.

4. Conclusions

IoT has improved our day today quality lives by major technical changes. IoT makes our life easy by use of multiple technologies and different kinds of applications. IoT provides augmentation and automation. IoT saves time, improves decision making, find usage in variety of applications and also saves money. IoT different application domains are healthcare, home automation, smart city, smart grid, smart vehicles, transportation, smart parking, smart infrastructure, industrial, manufacturing, business, governance, supply chain, logistics, education, agriculture and mining. IoT has multiple advantages. Various issues in IoT governance and its implementation are as under:

(1) Universal standardization is required in architecture
(2) Interoperable technologies are required
(3) Standard protocols are required

IoT vision and a well defined architecture for deployment is presented in this paper. We highlighted different enabling technologies and addresses security issues and challenges. IoT applications were discussed which improves and ease our daily quality lives. Research is going on in this area for wide scale IoT adoption. The issues and challenges needs to be dealt with and cleared. Security, privacy, confidentiality of information must be provided to the user. IoT deployment requires tremendous efforts by resolving the issues related to confidentiality, security and privacy threats.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Please cite this article as: P. Goyal, A. K. Sahoo and T. K. Sharma, Internet of things: Architecture and enabling technologies, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.678

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Please cite this article as: P. Goyal, A. K. Sahoo and T. K. Sharma, Internet of things: Architecture and enabling technologies, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.678

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