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Review

# Evolution of Internet of Things (IoT) and its significant impact in the field of Precision Agriculture

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ABSTRACT

During recent years, one of the most familiar name scaling new heights and creating a benchmark is Internet of Things (IoT). It is indeed the future of communication that has transformed Things (Objects) of the real world into smarter devices. The functional aspect of IoT is to unite every object of the world in such a manner that humans have the ability to control them via Internet. Furthermore, these objects also provide regular as well as timely updates on their current status to its end user. Although IoT concepts were proposed a couple of years ago, it may not be incorrect to quote that this term has become a benchmark for establishing communication among objects. In context to the present standings of IoT, identification of the most prominent applications in the field of IoT have been highlighted and a comprehensive review has been done specifically in the field of Precision Agriculture. This article evaluates contributions made by various researchers and academicians over the past few years. Furthermore, existing challenges faced while performing agricultural activities have been highlighted along with future research directions to equip novel researchers of this domain to assess the current standings of IoT and to further improve upon them with more inspiring and innovative ideas.

## 1. Introduction

During the past few years, the vision of the term Internet has been constantly expanding its wings in every aspect of life. It has become a challenging task for researchers to clearly identify the optimal potential of Internet usage. With the passage of time, the term of Internet has been associated with things and is now being identified as IoT. As the name depicts, things are associated thorough Internet via Wireless Sensor Networks (WSN), Radio-frequency Identification (RFID), Wireless Sensor Networks (WSN), Bluetooth, Near-field communication (NFC), Long Term Evolution (LTE) and various other smart communication technologies. Hence, IoT can be defined as “things that are associated over the Internet.” This association helps in transfer of information gathered from various devices to destined places over the Internet. Since IoT is the most reliable term of the technological world in today’s date, it still lacks through the potential compliance that it is actually capable of. In such a complex scenario, this article aims to assist to all those who want an easy and through an approach to understand the concept and further wishes to contribute towards its channelization to serve in the best optimal manner. This article depicts research articles related to the field of Precision Agriculture research using IoT, with maximum number of citations, in order to extract the most valuable content and distinct researches over the years. The most relevant among them have been addressed and discussed by length in this research article.

This article has been prorated in a total of five sections. Section 1 of the article is the introductory phase which sheds light on IoT, along with the reason for the motivation of going ahead with the review article. A continued proportion within this section also highlights the research methodology and classification technique adopted for documenting this article. Section 2 highlights the basics of IoT, along with its evolution, objectives and various communicational technologies. Section 3 addresses IoT applications. In this section, the focus has been only on research articles related to the field of Precision Agriculture. The articles have been extracted on the basis of the highest number of citations over the past few years. Table 4 in this section depicts Technique/Methodology proposed, Issues highlighted/addressed, Strength and Weaknesses and Table 5 depicts Communication technology, Observations conducted, Materials/Digital used, Location of experimentation, and Future scope of improvement for various research articles discussed. Keeping a view of existing scenario, all possible open issues, challenges and future research directions of modern day have

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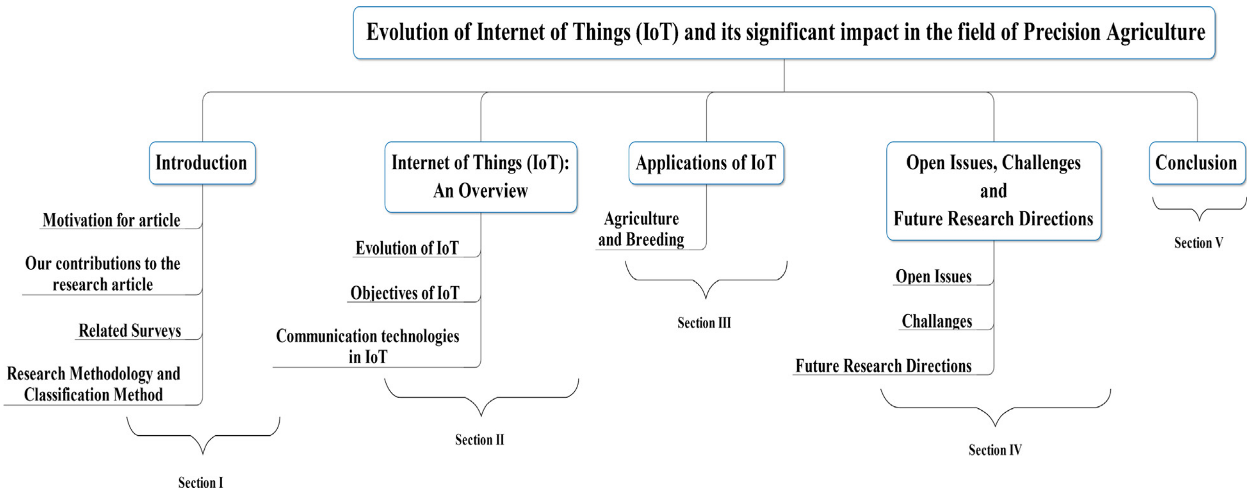


**Fig. 1.** Organizational structure of the article.

been discussed in Section 4. Section 5 is the concluding portion of the research article, depicting the crux of the research article. Fig. 1 depicts a pictorial representation of organizational structure for the article.

### 1.1. Motivation for article

Over the years, there are other survey articles written by eminent researchers in the field of IoT. However, it is a fact that technology is never static. Constant advancements and ever enhancing expectations from an existing terminology keep on motivating scientists and researchers to attain newer benchmarks. Moreover, during the last recent years, there has been an ample increase in the number of associated terminologies *i.e.* cloud computing, big data, IoT, *etc.* Therefore, keeping existing scenario of constant advancements in the field of IoT in mind, there was a dire need of revisiting the current standings and capabilities of the new age IoT concepts. This study highlights modern-day requirements and their remedial alternatives in the field of agriculture and meets precisely to the expectations based upon modern day IoT concepts.

Hence, the authors recognized the necessity of conducting a methodological literature survey after considering a progressive research done in the field of agricultural domain by utilizing the concepts of IoT. A summarized form of the most prized research done in the field of agriculture has been carried out from an existing database in order to correctly identify the present standings, challenges, issues faced by the subjective domain and its immediate remedial solutions proposed by incorporating the concept of IoT over the years, has been presented in the study.

### 1.2. Our contributions to the research article

The research article has been framed in such a manner that:

- The study brings forward the concept of IoT from its origin, along with various up-gradations from time to time.
- Various communication techniques used in IoT have been discussed by length.
- The study has been framed in a manner, that highlights the basics of the concept term and gradually covers the functional aspects of the domain and also highlights the limitations and challenges faced by the agricultural domain.
- Comprehensive observations have been made to study the concept of precision agriculture using IoT with respect to upward market keeping modern day's requirements in focus.
- Future research directions in the field of agriculture based IoT have been presented based on forthcoming challenges.

### 1.3. Related surveys

Related surveys by Atzori et al. (2010), Agrawal and Vieira (2013), Gubbi et al. (2013), Said and Masud (2013), Perera et al. (2014), Madakam et al. (2015), Al-Fuqaha et al. (2015), and Whitmore et al. (2015) are some of the survey articles published over the past few years in IoT domain. Atzori et al. has addressed the enabling technologies along with applications, and open issues faced in the field of IoT (Atzori et al., 2010). Agrawal et al. presented a paper in a wider context of IoT, mainly enabling the factors for integration in various technologies. Furthermore, key technologies involved in the implementation of IoT and its major application domain have been discussed (Agrawal and Vieira, 2013). Gubbi et al. presented the vision of IoT by enhancing the requirement for convergence of WSN, distributed computing and Internet directed at technological research community (Gubbi et al., 2013). Said et al. highlighted architectures, new age applications, and challenges faced by IoT (Said and Masud, 2013). Perera et al. discussed the significant growth of sensor deployments over the past decade in the field of IoT (Perera et al., 2014). Madakam et al. highlighted the basic requirements, characteristics and aliases of IoT. The study also highlighted the usages of IoT in our daily life (Madakam et al., 2015). Fuqaha et al. emphasized on protocols, enabling technologies, and numerous application issues in the field of IoT. The study also depicts the architecture of IoT along with various elements and communication techniques. Lastly, the study also highlights the challenges faced in the field of IoT (Al-Fuqaha et al., 2015). Whitmore et al. highlighted the identifying techniques, sensing technologies, networking and processing capabilities of IoT (Whitmore et al., 2015).

The research activities and advancements have persistently enhanced in the field of IoT over the years. Identifying the dire necessity for a methodical literature a survey that evaluates on basis of parameters, updated with modern trends and integrated with existing research, has been presented in the study. This survey article highlights the key findings from previous surveys and presents a fresh methodical literature review that evaluates and discovers the possible potentials on the basis of available research in the field of IoT.

### 1.4. Research methodology and classification method

The objective of this survey article is to correctly identify the current standings of IoT in Precision Agriculture. Research has been done thoroughly by examining the existing literature work done in the context. To give a firm foundation to the review article, the study depicts the origin of IoT, along with current standings, trends and technologies as well. The foundations of IoT had been accessed in an order to identify and to stay as close to the objective. Furthermore, the objective was to clearly identify how the concept came into existence with respect to agriculture domain and what is its current standings. The last objective of conducting an extensive research was to correctly identify the future directions for IoT by adding concerns of current enthusiasts in the field of IoT in agriculture. This comprehensive reference acts as a benchmark that assists in understanding the basics of the domain in a crystal clear manner and leads new age researchers in further excelling in this domain.

Hence to attain the objective, a thorough comprehensive review of all the identified literature has been done. The framework for the existing study is based on reviewing manuscripts from various conferences, journals, and edited volumes. Vital literature was identified and extracted by querying scholarly databases by searching keywords like "Internet of Things", "IoT", "Precision Agriculture", and "Smart Agriculture."

58 papers out of a total database of 272 papers were shortlisted after thorough reading. Each paper was discussed, analyzed, and classified to a specific domain category. The literature was distributed among both the authors on the basis of interest. Fig. 2 depicts the selection procedure for extraction of research articles on the basis of abstracts and keywords, whereas Table 1 highlights different e-resources accessed for acquiring in-depth knowledge for the domain.

The popularity of all the four different paradigms *i.e.* Internet of Things, IoT, Precision Agriculture, and Smart Agriculture varied from time to time. The web search popularity, as measured by the Google search trends for the past 8 years for the above said terms have been presented in Figs. 3 and 4.

It is clearly visible that, since the day term "Internet of Things" came into existence, the search volume for the same has been consistently increasing in contrast to its miniature term, "IoT". However, there has been a mixed response for the terms, "Precision Agriculture" and "Smart Agriculture". As per Google's search forecast, this trend for both is likely to continue for another couple of years and would be scaling newer heights, as more and more devices are being connected over the Internet on daily basis.

**Table 1**
Summary of data of papers selected on the basis of search string "Internet of Things, IoT, Precision Agriculture, and Smart Agriculture".

| Sr. no | E-resource | Content |
|---|---|---|
| 1 | www.springerlink.com | Conference, Journals, Proceedings, Transactions, Databases and Magazines |
| 2 | www.ieeexplore.ieee.org | |
| 3 | www.sciencedirect.com | |
| 4 | www.scholargoogle.com | |
| 5 | www.onlinelibrary.wiley.com | |
| 6 | www.acm.org | |
| 7 | www.webofknowledge.com | |
| 8 | www.elsevier.com | |

## 2. Internet of Things (IoT): an overview

During mid 80's the communication was either limited to voice over telephone lines or letters. With, passage of time, the term Internet came into being and communication got a new platform. The possibility of Voice over Internet Protocol (VoIP) was also achieved over the years. Today's era has left the concept of Internet far behind and has come up with the concept of IoT. IoT is a technique that combines existing resources to the Internet for obtaining control over the devices. The introductory concept of IoT was proposed at Massachusetts Institute of Technology (MIT) Auto-ID Labs in the early 1990s. However, Trojan Room coffee pot was the first IoT application; that was developed in 1999 (Jia et al., 2012). Later during the same year, world's first Internet controlled device, a toaster that could be remotely turned on and off over the Internet was developed (Welbourne et al., 2009; Zhang et al., 2012).

Over the years, there have been several definitions derived by various organizations working on IoT domain, across the world. Each organization has termed the definition of IoT in context to its functional advancement obtained over the years. ITU-T has termed IoT as, "Global infrastructure for Information Society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving, interpolatable information and communication technologies" (Elkhodr et al., 2013). Although IoT is all about a synchronization of

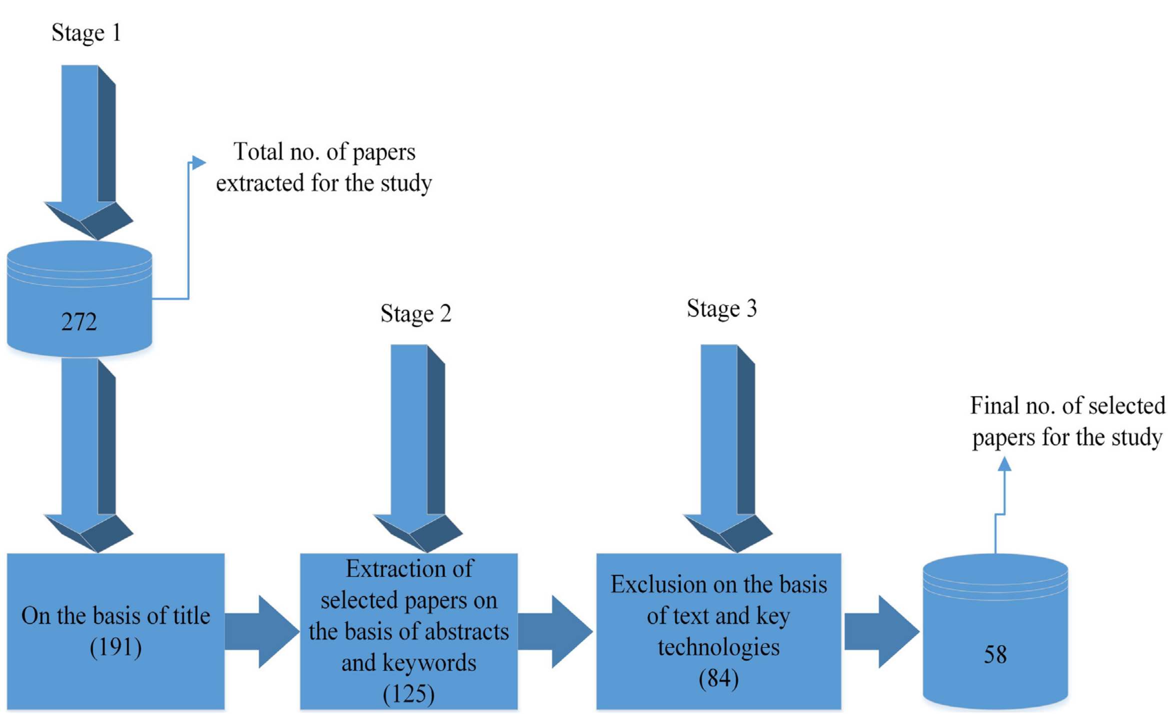


**Fig. 2.** Study selection procedure.

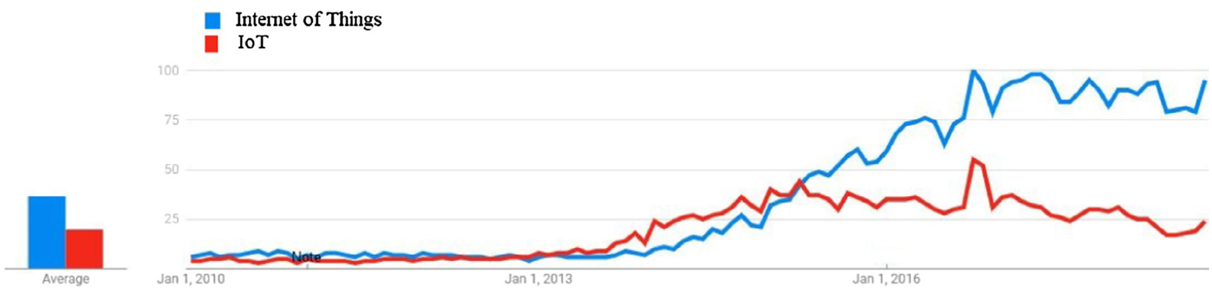


**Fig. 3.** Google Trends response for keywords "Internet of Things" and "IoT" for the last 8 years.

Things (Objects) over the Internet. It is the intervention of humans that makes this concept a possibility. Fig. 5 depicts the Tri-sectional relationship among the three aspects of IoT.

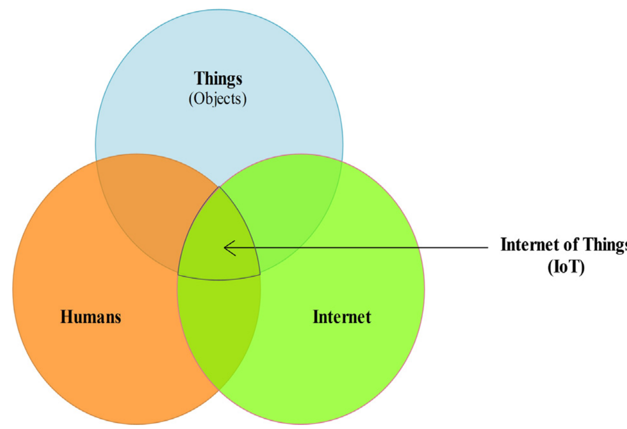


**Fig. 5.** Tri-sectional relationship among the three aspects of IoT.

With the passage of time and constant advancements in the field of Internet, many refined terms for Internet came into existence. The first phase was the Pre-Internet phase, where communication was possible over a fixed telephone line and via Short Message Service (SMS). Later the communication medium was upgraded with mobile telephony devices. The second phase was of Internet of Content phase. This phase was capable of sending large sized messages, *i.e.*, an e-mail that was capable of associating attachments, information, entertainment, *etc.* were the basic possibilities of this phase. The third phase was of Internet of Services, that focused on electronic applications like e-productivity, e-commerce, *etc*. The fourth phase, *i.e.*, Internet of People was the phase were people got associated with each other through social media and numerous other mediums like Facebook, Orkut, Skype, Youtube, *etc*. The ongoing era is of IoT. The functional aspect that has the capability of connecting devices over the Internet. Hence these devices can communicate among each another and perform a number of activities as directed/programmed according to design and functional capabilities of various objects.

However, the existing era might not be considered to be as the end of the road for the concept. Researchers are trying to incorporate the concepts of Artificial Intelligence (AI) upon these interconnected devices so that they can take necessary decisions and act upon without intervention of humans. It may not be incorrect to term the upcoming phase as Internet of Things powered by Artificial Intelligence (IoTAI). Transformation of Internet from Pre-Internet to IoT has been depicted in Fig. 6.

### 2.1. Evolution of Internet to IoT

Internet has undoubtedly become a benchmark in terms of communication. This terminology in today's date has taken control over billions of devices by incorporating sensor(s) based on their functional capabilities. These devices when connected via sensor(s) over the Internet, generate enormous data that is further processed for decision making. During the last few years, there has been a steep inclination towards adaptation of new age communication technologies. To date, the world is deployed with around 5 billion smart devices. It has been predicted that over 50 billion devices will be connected over the Internet by the year 2020 (Mainetti et al., 2011). It has been estimated that the incremental value of IoT would surpass $300 billion by the end of the decade. This boosts vision for the development of newer communication technologies and finding out new modes of getting synchronization of newer devices to sensors over the Internet. However, it may be incorrect to directly evaluate the functional capabilities of IoT, before understanding time to time changes and advancements in the field of IoT. Fig. 7 depicts a constant increase of devices being associated over the Internet during the last few years.

Since research on IoT is an area of interest for both academic and industrial sector, the outcomes depict the urge for constantly finding new methodologies for associating various devices over the Internet with help of additional sensors. This concept is now being looked upon as a roadmap for development in many of the areas of concern towards society, *e.g.*, Smart Mobility, Smart Grid, Smart Homes and Buildings, Public Safety and Environment Monitoring, Medical and Health care, Industrial Processing, Agriculture and Breeding, Independent Living are few of them. Fig. 8 depicts the constant increase of devices being associated over the Internet during the last few years.

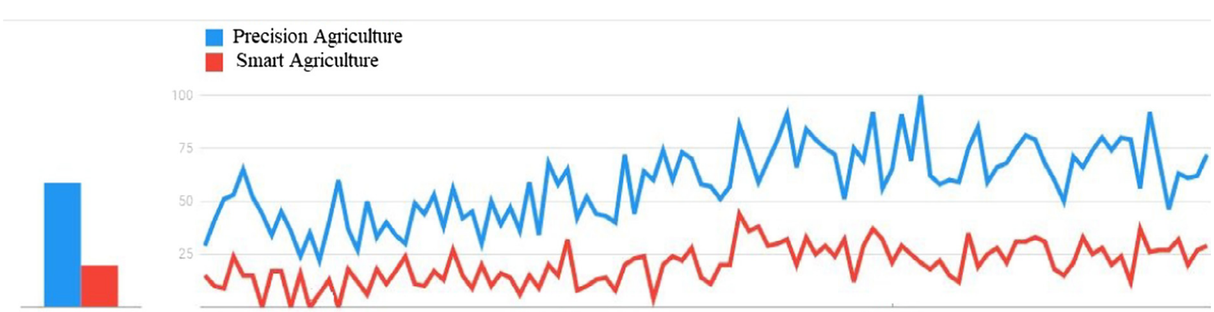


**Fig. 4.** Google Trends response for keywords "Precision Agriculture" and "Smart Agriculture" for the last 8 years.

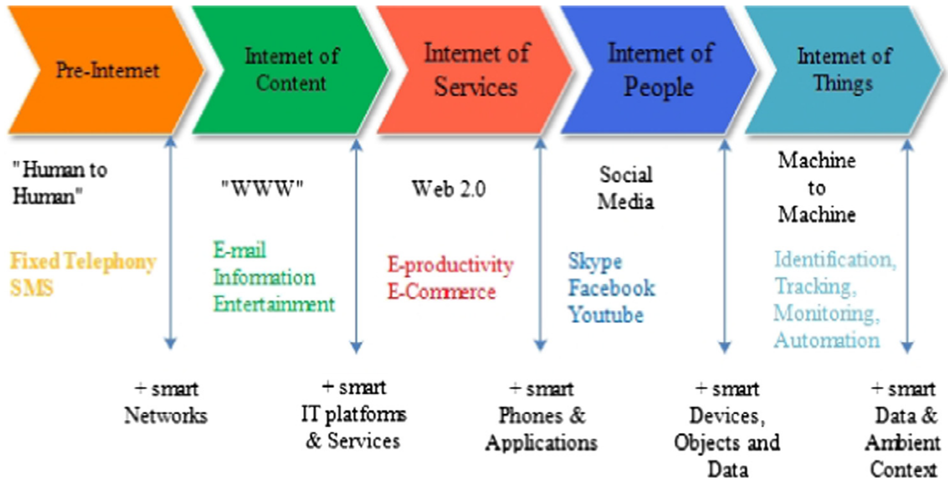


**Fig. 6.** Transformation of Internet from Pre-Internet to IoT.

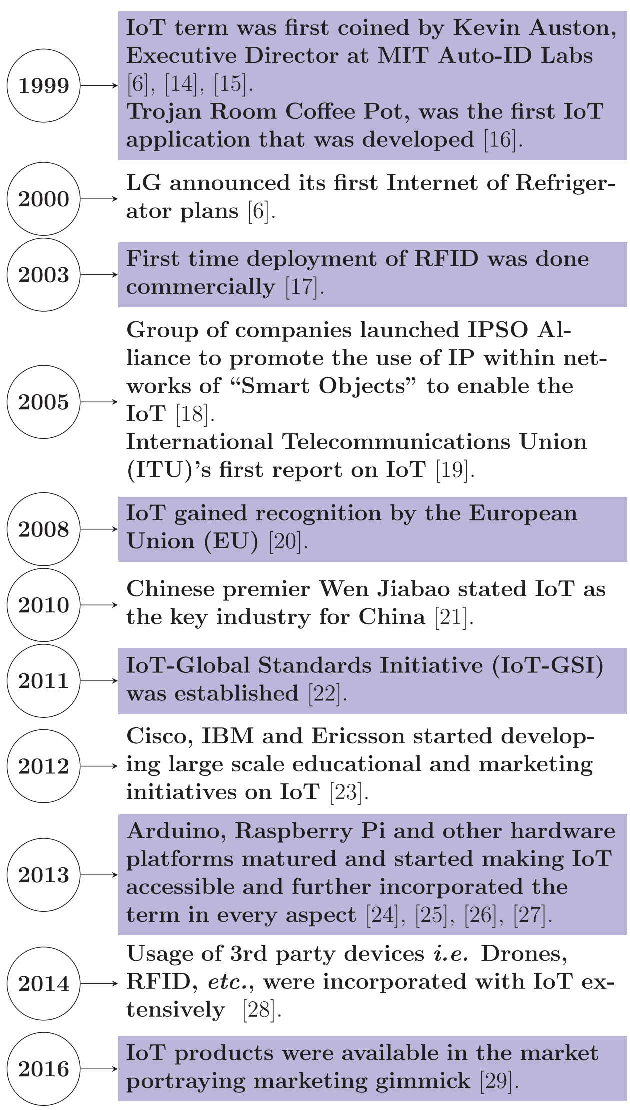


**Fig. 7.** Evolution of IoT (Ma, 2011; http://www.autoidlabs.org/; Abou-Zahra et al., 2017; Juels et al., 2003; Santucci, 2010; Gonzalez et al., 2008; Weber and Weber, 2010; Medeiros and Fravel, 2003; Meddeb, 2016; Kuyoro et al., 2015; Hodges et al., 2013; Evans et al., 2013; Shajahan and Anand, 2013; Tso et al., 2013; Wilkinson, 2014; Babin and Zikmund, 2015).

Garter's Information Technology Hype Cycle for the year 2018 also reveals that IoT platform tops the chart with respect to peak inflated expectations; that had initiated through an innovation trigger and has reached the maximum level of expectation, where the dependency rate and increased expectations persuade researches for newer developments. Fig. 9 depicts the Emerging technologies according to Gartner's Hype Cycle report.

### 2.2. Objectives of IoT

Since IoT is all about Universal Integration of things through an IP based Service Oriented Architecture (SOA) enabling heterogeneous components and their interoperability. IoT aims at attaining the following objectives:

- The research potentials are aimed to extend the capabilities from IPv4 to IPv6 and other related standards that are competent enough to support the future of IoT and to overcome its existing fragmentation issues.
- To develop a highly scalable IPv6-based SOA that is capable to achieve on issues like mobility, interoperability, cloud computing integration, and intelligence distribution among heterogeneous smart components, applications and their services.
- Self capable of exploring innovative forms of interactions with:
  - (i) Multi-protocol integration.
  - (ii) Self interoperability with heterogeneous devices.
  - (iii) Cloud Computing Services (IaaS, Paas, and SaaS).
  - (iv) Self-identification of RFID tags and other related services.
  - (v) Intelligent distribution systems.

### 2.3. Communication technologies of IoT

There exists an almost bewildering choice of connectivity options for modern day applications. These are based upon the products and systems associated with IoT. Major communication technologies in IoT have been depicted in Fig. 10.

#### 2.3.1. Radio-frequency Identification (RFID)

RFID system is composed of one or more reader(s) and several RFID tags. RFID tags are characterized by a specific address and applied upon objects. They make use radio-frequency electromagnetic fields to transfer data associated to an object as shown in Fig. 11.

These tags are embedded with electronically stored information which can be read by RFID reader when the object came in the proximity of the reader (Dominikus et al., 2010). RFID allows monitoring objects in real-time, without the need of being in line-of-sight. From a

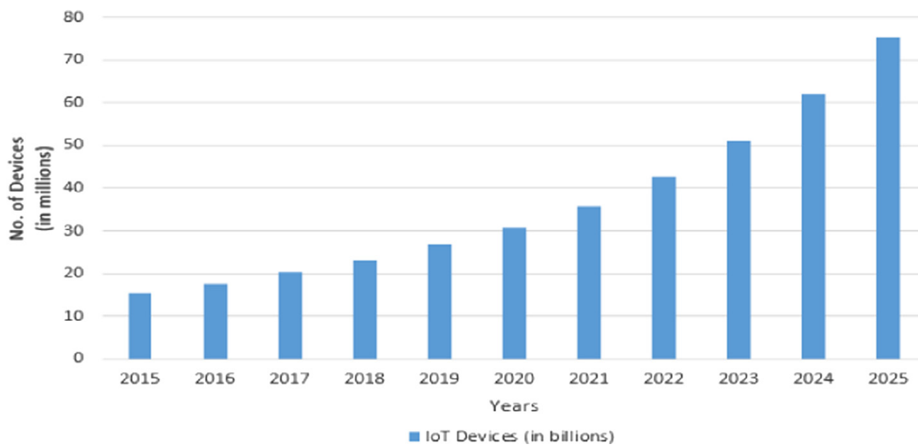


**Fig. 8.** Projection in number of devices being associated over the Internet (2015–2025) (Columbus, 2015).

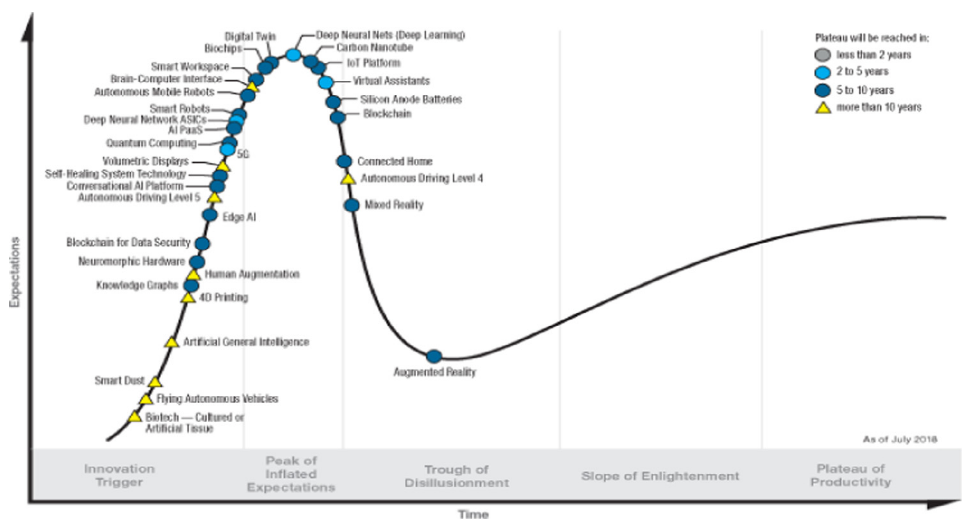


**Fig. 9.** Emerging technologies (Source: Gartner's Hype Cycle) (Moore, 2018).

physical point of view, RFID tag or a label is a tiny microchip combined with an antenna as a compact package. The tag antenna picks up signals from an RFID reader and then returns the signal, usually with some additional informative data. An RFID tag comes in three configurations. The first one is the Passive Reader Active Tag (PRAT) in which the reader is passive and receives the signal from the battery operated active tags, whereas the second one is the Active Reader Passive Tag (ARPT), which is most commonly used for communication purposes (Lapide, 2004). This tag does not have onboard power supplies, hence it harvests the energy required to send data from the query signal sent by the RFID reader. The last one is an Active Reader Active Tag (ARAT). An Electronic Product Code (EPC) is the most common set of data stored in a tag. EPC's are coded on RFID tags because of which objects can be tracked and identified uniquely. RFID is categorized in 4 different segments as depicted in Table 2.

### 2.3.2. IEEE 802.15.4

It is a standard which specifies the physical layer and media access control for Low-Rate Wireless Personal Area Networks (LR-WPANs). The original version of IEEE 802.15.4 supported 826 and 915 MHz frequency bands, while the working model supports 2.4 GHz ISM band. The basic framework conceives a 10 m communications range with a

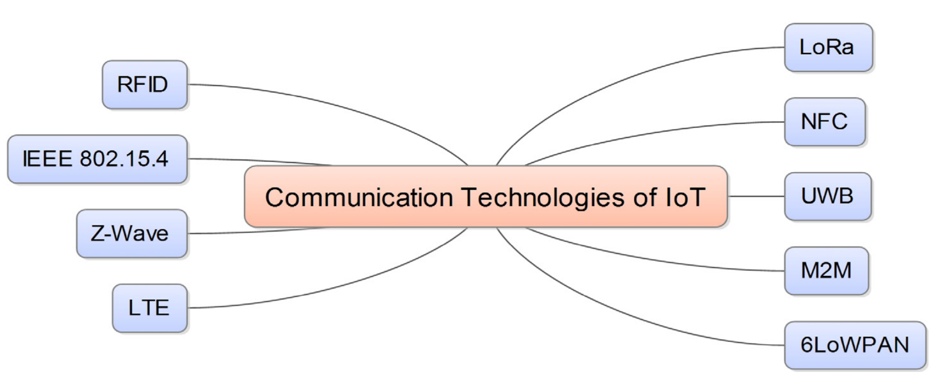


**Fig. 10.** Communication technologies of IoT.

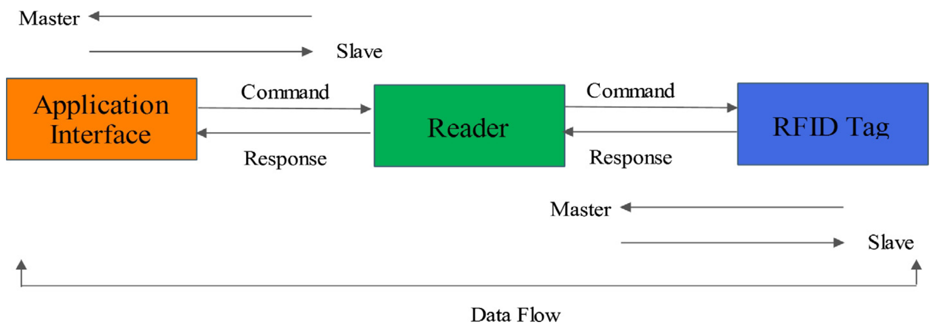


**Fig. 11.** Working of RFID.

**Table 2**
RFID categories.

| RFID type | RFID operating frequency |
|---|---|
| Low frequency | 125–134 kHz |
| High frequency | 13.56 MHz |
| Ultra high frequency | 860–960 MHz |
| Super high frequency | 2.45 GHz |

transfer rate of 250 kbit/s (Jiang, 2015).

#### 2.3.3. Zensys Wave (Z-Wave)

Z-Wave is a low-power wireless communication protocol for Home Automation Networks (HAN). It is used widely in the remote control applications for smart homes, as well as small-size commercial domains. In Europe, it operates at 868.42 MHz, whereas in Canada and the USA it uses 908.42 MHz bandwidth for communication. The distance between two nodes should not be exceeding 30 m.

#### 2.3.4. Long Term Evolution (LTE)

LTE is a standard wireless communication protocol for high-speed data transfer between mobile phones based on Global System for Mobile Communication (GSM) network technologies. It supports up to a maximum of 100 MHz. Data upload and download often encounter lower latency rate and higher throughout (YangDacheng, 2010).

#### 2.3.5. LongRange (LoRa)

LoRa is a digital wireless data communication technology, developed by Cycleo of Grenoble, France, and acquired by Semtech back in 2012. It is mainly used in long-range connectivity for various IoT devices used in rural, remote as well as in offshore industries. Apart from the above, LoRa is also used in various applications like supply chain management, transcontinental logistics, mining, natural resource management, *etc.* (Centenaro et al., 2016).

#### 2.3.6. Near-field communication (NFC)

NFC is quite similar to RFID. It is overlooked as an integration of RFID reader onto on a mobile phone. NFC is also be seen as a unique kind of a radio communication device that is enabled on mobile devices either by tracing inbuilt options that need to be activated or by the two devices close in the proximity (Bravo et al., 2007). From a technical point of view, NFC operates within a licensed radio frequency band of 13.56 MHz. The typical operating range of NFC device is 20 cm precisely. The operating range directly depends upon the size of the antenna within the device. NFC is a short range, low power wireless link evolved from RFID that can transfer small amounts of data between two devices held in proximity. Unlike Bluetooth, no paring is required before the actual transfer of data. NFC enables communication between two smart objects, that is safe, as this cannot be done from a remote location (He et al., 2015). NFC technology significantly contributes to the future development of IoT. It provides all the necessary attributes required for creating a wireless connection to smart objects. Furthermore, NFC also has the potential to transform the mobile headsets into different types of smart objects.

#### 2.3.7. Ultra-wide band (UWB)

UWB communication technology is designed to support communications within low range coverage areas, that is similar to NFC that uses low energy. However, high bandwidth is used for applications to connect sensors for communication. It is capable of a maximum of 500 MHz bandwidth. It was earlier known as radio pulse.

#### 2.3.8. Machine to Machine (M2M)

M2M refers to the communications either between computers, embedded processors, smart sensors, actuators or with mobile devices. Usage of M2M communication has been increasing at a fast pace during the last recent years (Wu et al., 2011). For instance, researchers predicted that, by the year 2020, there will be 2.5 billion wireless connected devices (excluding mobile phones). There are a total of five basic components of M2M communication technique: sensing, heterogeneous access, information processing, applications, and services (Severi et al., 2014). M2M is a five-part structure that constitutes of following parts:

- M2M Device: A device capable of replying to request data contained within that device.
- M2M Area Network (Device Domain): Provide connectivity between M2M Devices and M2M Gateways.
- M2M Gateway: Use M2M capabilities to ensure M2M Devices interworking and interconnection to the communication network.
- M2M Communication Networks (Network Domain): Communications between the M2M Gateway(s) and M2M application.
- M2M Applications: Contains the middleware layer where data goes through various application services and is used by the specific business-processing engines.

#### 2.3.9. IPv6 Low-power Wireless Personal Area Network (6LoWPAN)

A key IP is based on technology is 6LowPAN. This network protocol defines encapsulation and header compression mechanisms. The standard has the freedom of frequency band and physical layer and can also be used across multiple communications platforms, including Ethernet, Wi-Fi, IEEE 802.15.4 and sub 1 GHz ISM. This concept is specially designed for home or for building automation systems where it provides a basic transport mechanism to control complex control systems and to communicate with devices in a cost-effective manner via a low-power wireless network infrastructure.

Difference among various communication techniques of IoT on basis of standard, year of discovery, downlink/uplink of data, Table 3 depicts various comparative table for various communication technologies.

## 3. Applications of IoT

IoT has a lot of potential for social, environmental and economic

**Table 3**
Difference of frequencies and distance covered by various technologies used in IoT for communication.

| Technology | Standard | Year of discovery | Downlink/Uplink | Range (in metres) | Operating frequency (in MHz) |
|---|---|---|---|---|---|
| RFID | Wireless | 1973 | 100 kbps | 2 | 0.125–5876 |
| IEEE 802.15.4 | 6loWPAN | 2003 | 250 Kbps | 30 | 826 & 915 |
| Z-Wave | Wireless | 2013 | 100 kbit/s | 30 | 868.42 & 908.42 |
| LTE | 3GPP, LTE and 4G | 1991 | 100 Mbps | 35 | 400–1900 |
| LoRa | Wireless | 2012 | 0.3 37.5 (kb/s) | 3000–5000 | 169, 433 & 868 (Europe) & 915 (North America) |
| NFC | ISO 18092 | 2004 | 106, 212 or 424 Kbits | < 0.2 | 13.56 |
| UBW | IEEE 802.15.3 | 2002 | 11–55 Mbps | 10–30 | 2400 |
| M2M | Open to all communication protocols | 1973 | 50–150 Mbps | 5–20 | 1–20 |
| 6loWPAN | Wireless | 2006 | 250 Kbps | 30 | 915 |

impact towards its adaptation. IoT concepts have been adopted in a variety of domains ranging from Mobility, Smart Grid, Smart Homes/ Buildings, Public Safety and Environment Monitoring, Medical and Healthcare, Industrial Processing, Agriculture and Breeding and Independent Living are some of them.

All these applications are associated to us in one way or another. Usage of these applications and vivid benefits have an important role and now there is a huge dependency on their existence. They have indeed become an integral part of our lives. During the recent years, their existence and usability has attained visionary scale and have become of paramount importance. It may not be incorrect to state that the future of Internet is purely based on the concept and vision of IoT, which drives us into the future practically. Various application areas of IoT have been depicted in Fig. 12.

In this study, research work has only been carried out on basis of functional aspects in Agricultural domain based on prominent work done by various researchers and academicians over the past few years.

### 3.1. Agriculture and breeding

Precision Agriculture is an approach to farm management that uses Information Technology (IT) to ensure that the crops and soil receive exactly what they need for optimum health and productivity. The goal of Precision Agriculture is to ensure profitability, sustainability, and protection of the environment. Precision Agriculture is also known as Satellite Farming and Site-Specific Crop Management. Apart from the above said, there have been enormous changes in the techniques and methodologies of performing agricultural activities. The new age farmer has now moved from traditional farming to modernized concepts. Researchers working under this domain have come up with theories and practices that incorporate smart devices in order to evaluate the parameters that contribute towards the growth of plants and according to the observations, the agricultural activities are performed. Some of the major contributions under this domain are as follows:

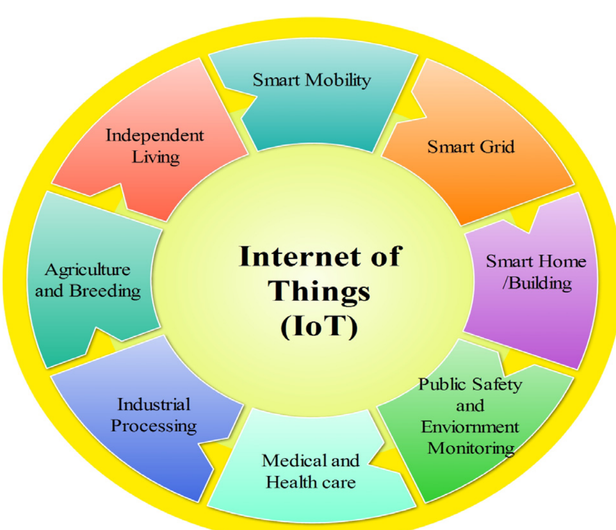


**Fig. 12.** Applications of IoT.

Zhao et al. (2010) projected the benefits of performing agricultural activities within a greenhouse technology. Furthermore, the process of automating the zone by incorporating the concepts of IoT technology. The authors highlighted incorporating of control through information networks within the test bed. Hence, a framework that combined both Remote Monitoring System (RMS) with Internet and Wireless Communications was proposed. The framework resulted in good growth and health of plants cultivated in greenhouse, which was easy to operate as compared to open fields (Zhao et al., 2010).

Bo and Wang (2011) proposed the usage of Cloud Computing techniques and its significant importance for IoT. The study proposed collaboration of two techniques in order to analyze the feasibility and future prospect of combination among both techniques. The experimentations carried out proved that a combination of these two technologies could successfully resolve problems and could eliminate development bottlenecks (Bo and Wang, 2011).

Bandyopadhyay and Sen (2011) proposed a state-of-the-art framework that highlighted the key technological drivers of IoT. The study also visualized the help farmers could obtain from IoT applications for acquiring information for delivering of crops directly to customers within small region (Bandyopadhyay and Sen, 2011).

Kaloxylos et al. (2012) in his study highlighted the importance of precision farming systems that played an important role in improving farming activities. A Farm Management System (FMS) has been proposed in the study (Kaloxylos et al., 2012).

TongKe (2013) highlighted the issues concerning agriculture. The study depicted one solution to the problems encountered for agricultural modernization. The authors proposed usage of IoT concepts and cloud computing techniques for performing agricultural activities. SOA and RFID technologies were also incorporated in the study (TongKe, 2013).

Ojha et al. (2015) depicted the advent of WSN techniques that spurred a new direction of research in the field of farming domain. The study highlighted the potential WSN applications along with various challenges and issues associated in the deployment of WSN for improved farming. Various case studies have been that presents the existing standings in the field of agriculture and furthermore, solutions have been proposed with regard to various problems (Ojha et al., 2015).

Bauer et al. (2016) in their study highlighted the scope of deployment of WSN for deriving vital crop information as it serves as a valuable indicator for yield-limiting processes. The study depicts the usage of Photosynthetically Active Radiation (PAR) sensors as it significantly enhances the potential performance of WSN technology for non-destructive in-situ Leaf Area Index (LAI) assessment (Bauer et al., 2016).

Ferrández-Pastor et al. (2016) in their study presented a low-cost sensor/actuator internetwork platform based on IoT that had integrated M2M and human-to-machine interface protocols. Although the experimentation was conducted within a greenhouse, the results of experimentation depicted that Internet technologies and Smart Object patterns could be combined to encourage development and further enhance Precision Agricultural activities (Ferrández-Pastor et al., 2016).

Jayaraman et al. (2016) in their study emphasized on a collection of agricultural data through various IoT devices such as WSN, network-connected weather stations, cameras, and smartphones. Furthermore, the study proposed a SmartFarmNet, an IoT based platform that was capable of automating the process of data collection from various parameters related to agriculture *e.g.* environmental, soil, fertilization, irrigation, *etc.* The proposed framework was also capable of correlating the data and filtering out invalid data from the perspective of assessing crop performance and further computation crop forecasts (Jayaraman et al., 2016).

Paustian and Theuvsen (2017) in their research article highlighted the importance of various techniques available in precision agriculture. The study also tends to gain insight into the relevant aspects of adoption of precision farming among various farmers in Germany on the basis of various characteristics and farmer demographics. The result of regression analysis depicts a positive influence on the adoption of precision farming among farmers. The results of the research article's study provided manifold starting points for the further proliferation of precision agriculture in various directions (Paustian and Theuvsen, 2017).

Balducci et al. (2018) aimed at managing heterogeneous data coming from various datasets by virtue of sensory values. The study also depicts how productive companies (large scale or small scale, public or private) are in a race of increasing profitability by virtue of costs reduction, discovering appropriate ways to exploit data that are continuously recorded and made available can be the right choice to achieve subjective goals. The study suggested usage of Neural network, Linear and Polynomial Regression Machine Learning models for decision-making and data handling (Balducci et al., 2018).

Hamad et al. (2018) highlighted the role of usage of smartphones for accessing agricultural information on various parameters and its advantages in the field of agriculture. A total of 230 farmers across the region were interviewed and primary structured questionnaires were filled. The study highlighted that most of the farmers suggested usage of smartphones for acquiring data on current farm conditions and also relied on adopting newer agricultural techniques depicted on videos available in the field of Precision Agriculture (Hamad et al., 2018).

Table 4 presents various Technique/Methodology proposed, Issues highlighted/addressed, Strength and Weaknesses, whereas Table 5 depicts Communication technology, Observations conducted, Materials/Digital used, Location of experimentation, and Future scope of improvement for various articles discussed in this section.

Fig. 13 depicts head count of various topics of interest related to research articles discussed in current study. The head count even depicts that there is a lot of inclination towards the term, "IoT in Agriculture" in comparison to any other topic.

## 4. Open issues, challenges & future research directions

### 4.1. Open issues

Irrespective of the rise that IoT has attained over the past few years, there are several conceptual and fundamental issues pertaining to its proper management and performance.

#### 4.1.1. Availability

Realization of IoT must be on the basis of existing hardware and software, so that they can provide anytime, anywhere access as well as services. IoT at times is misunderstood by many as a software application that is capable of providing services. The hardware part is equally important and is indirectly associated that functions with the help of various protocols such as 6LoWPAN, IPv6, CoAP, RPL, *etc*. The entire setup is often understood as a different unit. Hence an awareness of association among hardware and software by its end users can contribute towards channelizing the vision in a much more effective way.

#### 4.1.2. Reliability

The basic aim of having an enhanced reliability is to increase the success rate of IoT service, by virtue of its capability of delivering information. Hence a series of checks are required to be implemented over the hardware and the software part of the IoT framework. A shortcoming due to system failure or threats from intrusion always keeps the reliability of the framework as one of the major challenges in IoT.

#### 4.1.3. Mobility

Mobility is another challenge for smooth implementation of IoT as most of the applications are based on mobile interface. Since connectivity also plays a vital in the mobility of data. Hence, a failure in connectivity among non-stationary devices is often taken as an incapability on IoT for not being capable enough to transfer the data from origin to destination.

#### 4.1.4. Data confidentiality

Another challenging issue in the field of IoT is securing the data on all parameters. With the usage of various communication devices, the data travels over the Internet medium from source to destination. Issues related to data breach are always persistent. Hence maximum emphasis is given securing the data on all parameters.

#### 4.1.5. Management of Network and its resources

As projected over the next few years, everything that physically exists will be connected over the Internet. Hence managing numerous devices over a variety of networks and maintaining its resources will be a challenging task.

#### 4.1.6. Scalability

It refers to the concept of adding newer devices over the existing infrastructure without affecting the services and functional capabilities of the existing framework. Hence, scalability always remains a challenging task to achieve with collective consensus.

#### 4.1.7. Interoperability

To handle a large number of heterogeneous devices it is indeed a difficult task. Moreover, issues are also faced at the time of establishing a synchronization among different platforms. Hence, interoperability often remains an issue with respect to IoT.

#### 4.1.8. Security and privacy

Since the concept of IoT is designed to transmit information over the Internet, data privacy always holds a special significance. A lot of research works goes in making the data transmission completely secured, however, shortcomings do occur at times (Alaba et al., 2017).

#### 4.1.9. Software Defined Network (SDN)

Over the years, the concept of SDN has been incorporated in many aspects on many of the aspects of life. It is an approach that allows network programmers to initialize, control, change and manage the work behavior dynamically via interfaces. These concepts work on simulation and or real-time basis. SDN function-ability is based on responses from Data Center Networks (DCNs) and available IoT environments (Qin et al., 2014). Although the network is effective, flexible, and efficient; there persist some associated threats and challenges that cannot be overlooked.

#### 4.1.10. Virtualization

There are a lot of concerns related to the creation of a virtual version in order to eliminate the ongoing concerns of modern day applications.

**Table 4**
Technique/Methodology proposed, Issues highlighted/addressed, Strength, and Weaknesses for Agriculture and Breeding domain.

| Citation reference | Technique/Methodology proposed | Issue highlighted/addressed | Strength | Weakness |
|---|---|---|---|---|
| Zhao et al. (2010) | Remote Monitoring System framework proposed in the study | Issues related to control and managing of IoT technology in the field of agriculture | The proposed framework collected data that provided for agricultural research and management facilities | Study and its results are limited to greenhouse |
| Bo and Wang (2011) | Approach to analyze the application of Cloud Computing and IoT in the field of agriculture and forestry | Exploring the feasibility of synchronization of agricultural data on cloud server | Modern-day concepts and equipment were used for developing the framework | The proposed framework required technical knowledge, that farmers lagged upon |
| Bandyopadhyay and Sen (2011) | The study highlighted various technical challenges and their standardization in the field of IoT in agriculture | The study highlights issues related to non-availability of connection channel/medium among farmers and end consumers | A wider spectrum of various challenges and techniques to overcome them was depicted in the study | Non-availability of channel leads to an indirect connectivity among farmers and end users |
| Kaloxylos et al. (2012) | Farm Management System (FMS) proposed in the study to be in synchronization with continuous up-gradations in the field of agriculture | Handling a vast number of networked devices within the fields | Proposed model provided easy access to required information and provided an automatic coordination and management among tractors in open fields | – |
| TongKe (2013) | Combination IoT concepts with Cloud Computing techniques for optimizing field activities were proposed in the study | Issues related to agriculture, countryside, and farming have been the prime objective to overcome | Detailed analysis of cloud computing in IoT has been done The architecture of agricultural information cloud along with Control architecture and Data center architecture has been discussed in the study | – |
| Ojha et al. (2015) | Study highlights importance of WSN in the field of agriculture | Issues related to proper deployment of WSN for agricultural domain have been discussed by length | The study highlights various issues encountered while deployment of various agricultural sensors and also provides its remedial solutions | – |
| Bauer et al. (2016) | WSN based approach using LAI as key parameter | To overcome the saturation issue of LI-COR's approach | Simple, effective and cost-efficient approach | Experimentation has been done only on flat-leaved crop types |
| Ferrández-Pastor et al. (2016) | Message Queue Telemetry Transport (MQTT) protocol proposed in the study | To overcome the issue of generating a request for pushing the data to cloud | Easier to install, control and maintain | – |
| Jayaraman et al. (2016) | SmartFarmNet application | Issues related to manual collection of data, for evaluating crop performance | Proposed framework was capable of making predictions related to crop performance and further computation of crop forecasts | – |
| Paustian and Theuvsen (2017) | The authors had applied binary logistic linear regression on various farm characteristics and farmers demographics to predict the positive and negative influences on adaptation of precision farming among German farmers | To overcome an exert of negative influence on the adoption of precision farming among farmers having land less than 100 ha | In-depth data collection and analysis for various farms and farmers across the country has been done A positive influence and acceptance of adoption of precision farming practices among farmers | Authors have experienced a lack of interest in the adaptation of modern farming techniques due to significant variation in prices for various agricultural devices |
| Balducci et al. (2018) | Neural Network, Linear and Polynomial Regression Machine Learning Models have been discussed by length for performing correct analysis of agricultural data | Detection of faulty monitoring stations by analyzing their sensor values | Choosing of correct model resulted in favorable and authenticated results | – |
| Hamad et al. (2018) | Statistical Package for Social Sciences (SPSS) for evaluating farmers interest in the usage of smartphones for Precision Agriculture | Understanding the perception of farmers regarding the usage of smartphones in performing agricultural activities | Results obtained after applying Chi-square test depicted positive perception of farmers towards usage of mobile phones in agricultural domain | Lack of trust and high cost of smartphones within the country |

**Table 5**
Communication technology, Observations conducted, Materials/Digital used, Location of experimentation, and Future scope of improvement for Agriculture and Breeding domain.

| Citation reference | Observations conducted | Communication Technology | Materials/Devices used | Location of experimentation | Future scope of improvement |
|---|---|---|---|---|---|
| Zhao et al. (2010) | RT | TCP | WSN, Autonomous Sensors, and RFID | Beijing, China | Implementation of same technology over other varieties |
| Bo and Wang (2011) | RT | IP-based infrastructure and UDP | WSN, and Zigbee | Beijing, China | Scope for improvement in large-scale farms and increase in reliability, expandability, economical, practical, and a higher rate of efficiency |
| Bandyopadhyay and Sen (2011) | RT | Near field communication | RFID tags, and Agricultural sensors | Kolkata, India | Proper identity identification and management of devices associated over the Internet |
| Kaloxylos et al. (2012) | RT | NA | RFID, Sensors, and ZigBee | Athens, Greece; Munich & Kaiser-slautern, Germany; Vihti, Finland and Wageningen, The Neatherlands | Possibility of adaptation of newer characteristics in the field of agriculture |
| TongKe (2013) | RT | IEEE 802.4 protocol | Sensors, Actuators, and Zigbee | Shaanxi, China | Complete adaptation of IoT based cloud computing techniques |
| Ojha et al. (2015) | RT | Zigbee, IEEE 802.11, and Bluetooth | RFID, M-RFID, Sensors, and Actuators | Kharagpur, India | Authors suggested further development of low cost autonomous solutions |
| Bauer et al. (2016) | RT | IEEE 802.15.4 | Photosynthetically Active Radiation (PAR) sensor | Osnabrck, Germany | Experimentations on different crops with PAR sensor |
| Ferrández-Pastor et al. (2016) | RT | Wi-Fi, Bluetooth, and 4G LTE | Smart Phone and Wi-Fi router | Alicante, Spain | Algorithms based on expert systems and Artificial Intelligence (AI) have been planned for the existing experimental station |
| Jayaraman et al. (2016) | RT | OpenIoT X-GSN | Agricultural and Environmental Sensors | Melbourne, Australia | Deployment of smart caching approach that can make autonomous decisions based on query patterns |
| Paustian and Theuvsen (2017) | RT | Standardized online questionnaire through Enterprise Feedback Management Platform | Agricultural online portals, emails, newsletters from local farmer associations, and social networking sites | Goettingen, Germany | The study provided scope for addressing farmers on key issues faced by them while performing agricultural activities in general and to further motivate them in adopting precision agriculture |
| Balducci et al. (2018) | RT | Clustering was based Euclidean distance that had similar geographic attributes | IoT based sensors | Bari, Italy | Further scope of improvement on services provided to end customers |
| Hamad et al. (2018) | RT | Structured questionnaires, focus group discussion through participatory rural appraisal, and observations | Secondary data was collected from scientific journals, books, and authenticated web sources | North Kordofan, Sudan | Eliminating issues related to the language barrier (information available regarding farming online), network problems in some areas of the country and difficulties in dealing with technology are some of the parameters that need improvement |

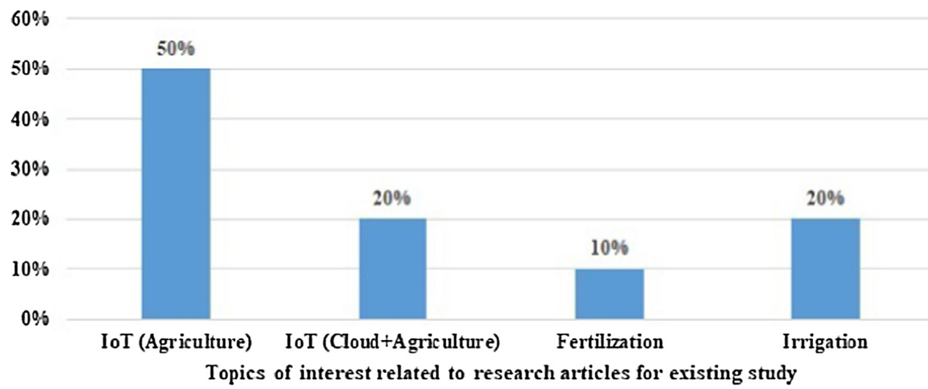


**Fig. 13.** Topics of interest related to research articles for existing study.

Its development, proper deployment and adaptability to existing scenarios are one of the biggest issues faced by IoT (Nastic et al., 2014).

#### 4.1.11. Standardization process

Standards are incorporated so that they can support numerous range of applications. Even with the use of semantic ontologies, machine-readable codification does occur at times which initially results in differences and misinterpretation due to different scenarios encountered from time to time. Still, there is a need to develop standards for an appropriate usage of IoT in various applications (Bandyopadhyay and Sen, 2011).

#### 4.1.12. Working ability and performance

Evaluation of functional capability and performance of IoT services are considered to be a big issue. Since performance is directly associated with the underlying technologies, it is very much mandatory to keep services updated from time to time so as to meet the requirements of the end users. Another factor is the evaluation of performance which is directly associated with the price and quality of underlying technology. However, the end user wants the best of performance with less of investment, the issue of evaluation of the performance of any IoT application remains an open issue.

#### 4.1.13. Compatibility with fifth generation (5G) communication

Even though when the high-speed communication system is facing a rapid transformation, major innovations always rebuked by some of the commonly faced issues by 5G communication technique for IoT based implementations. Some of the most commonly faced issues are enabling physical layer techniques of modulation, timely handling of multiple input multiple output and error control coding (Yilmaz et al., 2016).

Although a lot of efforts have been carried out in the name of IoT. There are still a number of aspects on which IoT needs to Díaz et al. (2016). A constant increase of interest by various academic, industries and other related bodies associated directly or indirectly with the field of IoT keeps on adding expectations that often leads to enhancement of challenges without realizing the basic requirements and functional capabilities of IoT. All the issues may be related to existing pitfalls of IoT. Constant advancements have been incorporated from time to overcome the ongoing issues as an extended face of lessons learned in terms of development of IoT.

### 4.2. Challenges

Most of the IoT applications within themselves allow identification of research and development challenges after outlining a roadmap for the future research activities in order to attain a reliable as well as practical solution. The road map has been formed on the basis of correct identification of research priorities based on evaluation on following identifiers:

- Complete understanding of IoT Architecture.
  The biggest challenge in SOA is to become imperative for the providers and requesters to communicate meaningfully with each other irrespective of being heterogeneous nature.
- Identification of correct technology for establishing the communication interface.
  Its main challenge is to map a unique identifier (globally unique or unique within a particular scope), to an entity so as to make it without ambiguity identifiable and retrievable.
- Establishment of a robust communication interface
  Some of the biggest challenges faced while establishing a well-oriented communication among the object and interface are:
  – Proper deployment of devices on objects.
  – Constraint free communication environment.
  – Cost.
  – Heterogeneity.
  – Communication modality.
- Correct identification and implementation of network technology.
  Correct implementation of the vision in order to reach out to objects of the physical world so as to bring them onto the Internet.
- Ability to identify and pair to a correct network.
  Overcoming the existing network dynamically so as to change the continuous evolving of things, so that they can feature varying degrees of autonomy.
- Correct identification of data received and further signal processing
  There is an enormous data generation when objects are synchronized over the Internet with the help of communication devices. Hence following concerns are of paramount priority:
  – Semantic interoperability.
  – Correct service discovery.
  – Service composition.
  – Data sharing and collaboration.
  – Correct identification of autonomous agents.
- Standardization
  Standards are to be designed so that they support a wide range of applications and address common requirements of all the possible applications that are inter-related to IoT.

Since IoT mainly evolves around synchronization of devices over the Internet, constant advancements from time to time in every domain indirectly invites some associated issues along with updates, which can neither be ignored nor can be overlooked (Wu et al., 2010). Based on the roadmap of identification of correct technologies (Khan et al., 2012; Gan et al., 2011), most basic encountered challenges are described as follows:

- Uninterrupted network connectivity.
- Acquisition of complete informational service.
- Uninterrupted operational service.

- Security related issues.
- Proper management of on-going services.
- Correct identification of services.
- Standardization.
- Inter-portability.
- Information Privacy.
- Physical safety of objects.
- Data confidentiality.
- Data encryption.
- Dedicated spectrum.
  On the basis of the most commonly encountered issues, some of the most prominent challenges have been identified specifically in the field of precision agriculture. They are as under:
- Sensor placement is at physical locations.
- Need to be cautious while performing agricultural activities.
- Lack of awareness among farmers.

### 4.3. Future research directions

The concept of IoT has come a long way, over the past few years. Resources available under the hood of IoT have fallen short and the existing scenarios further initiate to a number of queries that in one way or another, needs to be addressed before scaling newer dimension. Keeping in view of ever-increasing spectrum of IoT, some future related queries have been presented that needs to be addressed before we find ourselves enclosed within a new horizon.

- What would be the next big step to correctly identify and handle the huge range of devices that are being added over the Internet?
- How will the next generation of information systems work in synchronization with IoT, specifically when the technology is not constant?
- How will the newer concepts overcome the inherent complexity and data volume for providing a useful Decision Support Systems?
- Which IoT business model will drive the next generation's global business and commerce?
- Will the objects (things) only rely upon only Internet services for communication, in near future?
- What is the next big thing post IoT era?

## 5. Conclusion

This research article brings forth a comprehensive literature survey on the concept of IoT specifically in the field of precision agriculture. Furthermore, the study represents a detailed literature review keeping IoT as the supporting backbone for the concerned application highlighting author's viewpoint on issues faced, proposed methodology with various other informative details related to research articles under study.

The following conclusions can be further drawn from the study:

- IoT is contributing significantly in the area of modern agriculture.
- It helps farmers to control their farms remotely and manage agricultural activities in a more effective way.
- Since technology is not static, a newer dimension of IoT would be overtaken in near future.
- Data generated by various sensors is of paramount importance and needs to be managed and evaluated with a high level of precision.
- In the next few years, major agriculture sensors, actuators and devices would be connected over the Internet with the basic objective of interaction, controlling, and decision making. This will minimize human effort, save time, increase yield and profits.
- Extensive research in the field of IoT and Precision Agriculture will take a gigantic leap for the betterment of mankind.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.compag.2018.12.039.

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