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The Internet of Things: Insights into the building blocks, component interactions, and architecture layers

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Abstract

This paper deals with the internet of things (IoT) which has become a promising and vibrant technology to build power full smart systems to monitor and analyze various real time operating systems. In recent years a wide range of IoT applications have been developed. To understand the IoT concept, this paper studies the insights into the four building blocks of IoT (Things, Gateways, Network infrastructure, and Cloud infrastructure), three main components of IoT (The Things with Networked Sensors and Actuators, Raw Information and Processed Data Stores, and Analytical and Computing Engines) along with architecture layers (Three Layer, Five Layer, Six Layer, Seven Layer, Cloud, and FOG). The interaction between three components of IoT is also presented. The main contribution of this paper is that it summarizes the IoT, IoT building blocks, components and their interactions along with architecture layers systematically.

Keywords: IoT; The Internet of Things; IoT building blocks; IoT components; IoT architecture layers; features of IoT.

1. Introduction

The present world is more driven towards the automotive and digital era hitting the concepts of digital life. Internet and wireless networks have played a major role in the digital era. Before this, the control is mainly human to machine oriented and the execution of task would take much time. In the digital life, the main motto is to reduce the efforts between human to machine interaction and increase the machine to machine interaction abilities using the advanced technologies[1]. Regarding it, the communication and information technologies have become a paradigm introducing the concepts like wireless control, remote monitoring etc. making it a less burden to the human or the

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work force. With the advancements in wireless communications, intelligent computing, and network connectivity a novel and new technology called Internet of Things was introduced[2]. It had gained wide range of audience both from industry and academia spreading the technology towards various scientific applications both in science and engineering. The design and implementation of IoT for specific application might vary, however there exists a general architecture procedure to be followed for the implementation of IoT projects[3]. In this paper, to make the audience clear about the IoT concept, the basic building blocks of IoT is discussed along with its features. Further the IoT system working is explained by considering the IoT components and their interactions. A brief study on the architecture layers of the IoT systems were clearly stated in the paper.

Article is structured is as follows: in section-2, a brief about IoT and its contributions to the real time applications were dealt. Section-3 describes about the building blocks of IoT, components of IoT, and how the interaction between these components exists etc. highlighting their features. In section-4, various IoT architecture layers were discussed focusing on the layer functioning. Apart from this FOG and Cloud Layer concept in IoT is also described, Finally in Section-5, the paper is concluded giving the future scope chances and usefulness of the work presented in the paper.

2. The Internet of Things (IoT)

The Internet of Things (IoT), an evolutionary technology that raised and gained huge scope in the science and engineering applications solving problems without the intervention of human-machine physical contact. Advancement in internet technologies allowed the scope for wider and strong network connectivity between the objects[4]. In IoT every object is identified as a node and are connected through each other in a network, this sought of system allows the information sharing such as receiving and sending. To make it much clear, the objects in real time systems are equipped with the sensing elements, micro-controllers, communication elements, information storage and retrieval facility, and apt protocol[5,6]. These allows to have seamless and actively communicated information network which is very strong and integrated to each object and IoT system[7]. Fig. 1 clearly narrates the definition of IoT integrating all the possible aspects of communications and information sharing process between various objects.

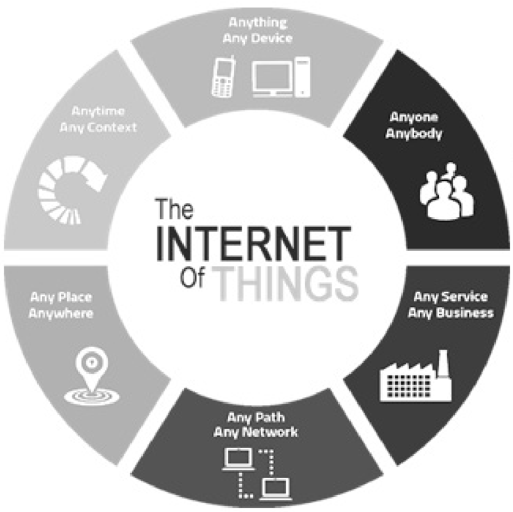

Fig. 1. Over view of the internet of things (IoT)[8] (Source: Sharp Node)

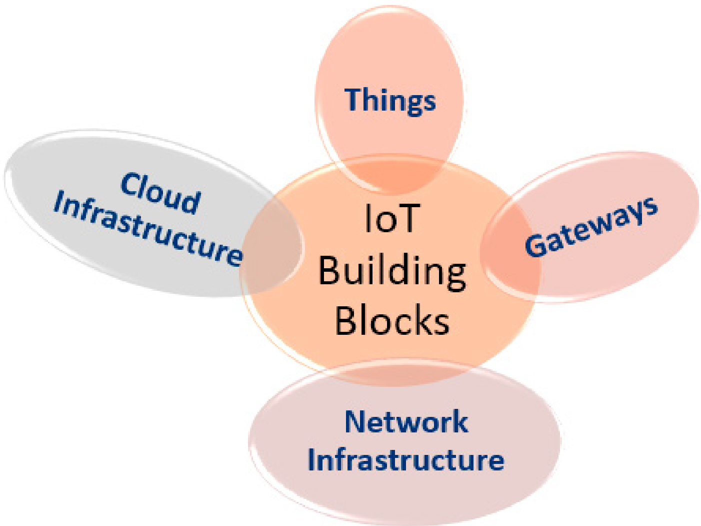

Fig. 2. Building blocks of internet of things

3. IoT Building Blocks and Components

IoT can be clearly explained with its architecture which would vary depending upon the specific application where it is adopted. However, its architecture is well explained by considering the concept called building blocks of IoT. Building blocks of IoT will be similar and can be capable explaining and designing a IoT hardware integrating with wide range of applications. Insights into the building blocks and components and their interactions were explained and dealt in the subsequent sections below.

3.1. IoT Building Blocks

IoT implementation include the four main building blocks, shown in Fig. 2. These include the Things, Gateways, Network Infrastructure (NI), and Cloud Infrastructure (CI)[9]. Here, things are the concentrated areas where information is sensed with the sensor elements or the actuators. Gateways block is used for the connectivity purpose and it is an intermediate block between the things and network or cloud infrastructure. Network infrastructure (NI) block helps in providing the control over the information provided and allows secure and smooth flow. Cloud infrastructure (CI) equipped with the information storage and computing proficiencies. Table 1 presents the features and basic IoT devices that are used in the four IoT building blocks.

Table 1. IoT building blocks, devices and its features.

IoT building blocks	IoT devices	Features
Things	Sensors, Actuators	Allows to communicate and collect the information from the objects of focused areas without any human interaction.
Gateways	-	Acting as an intermediate block and enables the strong connectivity between the things and cloud infrastructure.
		It also provides the security and manageability abilities during the data flow.
Network infrastructure (NI)	Routers, Aggregators, Gateways, Repeaters	It allows the control over the data flow from things to the cloud infrastructure.
		It also enables the security during the information flow.
Cloud infrastructure (CI)	Virtualized Servers (VS), Data Storage Units (DSU)	It allows the analytical, logical, and advanced computing abilities.

3.2. Grouping of IoT Building Blocks into Components

For easy understanding of the IoT implementation and the process flow, the above four building blocks are grouped into the three components. Now the three main components of IoT include: The Things with Networked Sensors and Actuators (TNSA), Raw Information and Processed Data Stores (RI-PD-S), and Analytical and Computing Engines (ACE). Features of the IoT components is presented in Table 2.

Table 2. Features of IoT components

IoT components	Features
Things with networked sensors and actuators (TNSA)	Collects the information from the objects or the things that were concentrated as per the specific application area
Raw information and processed data stores (RI-PD-S)	Stores the collected information in various forms: data, text, videos, images, models etc.
Analytical and computing engines (ACE)	It helps in the human-machine interactions and allows the feedback as per the human requirements. The also allows the analysis as per the computing model chosen based on the requirements.

3.3. IoT Component Interactions

The three components of IoT were clearly mentioned along with their features in Table 2. The interaction between these three components is portrayed in Fig. 3. The interaction between the IoT components starts from the Things with Networked Sensors and Actuators where they sense the detailed information as per the user requirements. The information sensed here might be with respect to time duration set by the user. The sensed information is then stored in the second component of IoT i.e. Raw Information and Processed Data Storage allowing an interaction between the TNSA and RI-PD-S. The interaction is enabled by sending the report states and the information is stored in various formats such as data, text, videos, and images etc. The third components of IoT is the Analytical and Computing Engines (ACE) where the stored information is analyzed logically with appropriate decisions using numerous models there by allowing an interaction between the RI-PD-S unit and ACE. This logical analysis is done with multiple iterative procedures until the best results achieved as required by the user. In this third component human-machine interactive learning is possible along with cloud and server-based analytics. Based on the human-machine interactive learning, the feedback and control commands or requests were given to the Things with Networked Sensors and Actuators component there by allowing interaction between TNSA and ACE[10-12].

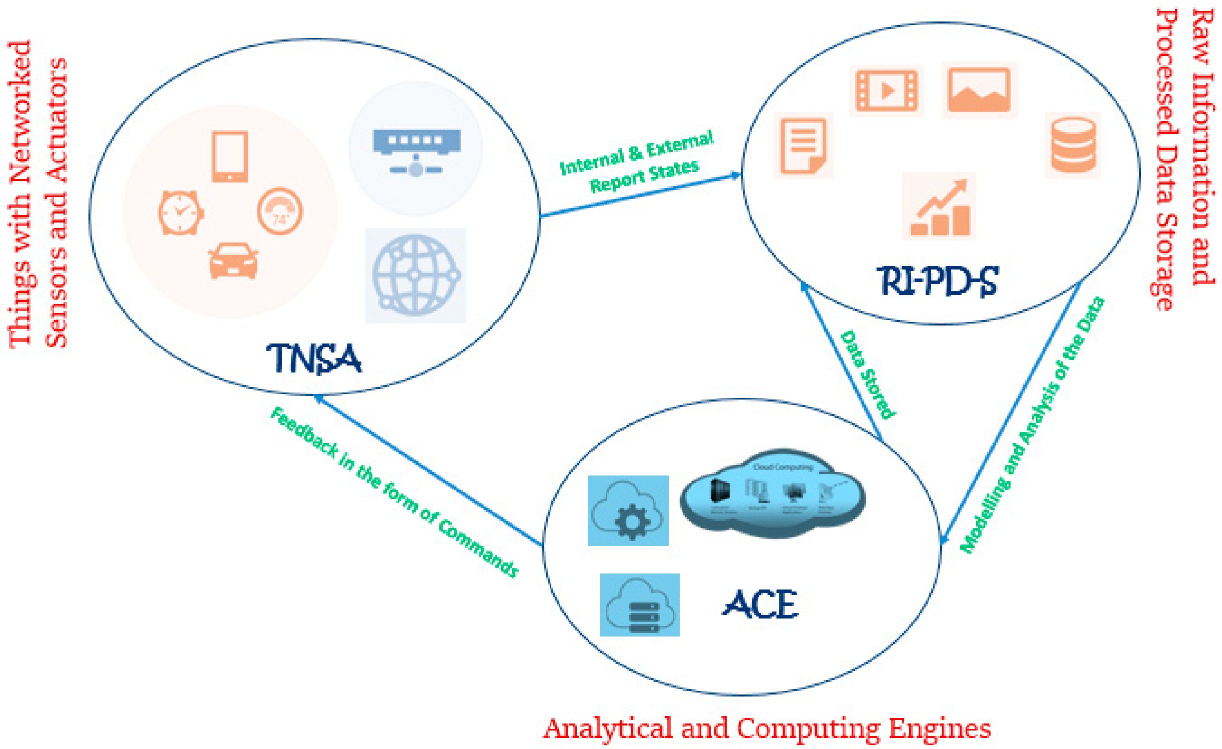

Fig. 3. IoT component interactions

4. IoT Architecture Layers

The internet of things provides fascinating solutions to most problems that workforce is facing. The approach of attaining a solution is based on how the information technology components were integrated with communication devices with best hardware and software convergence. Here in IoT, the software and hardware components act and work mutually with the learned outcome-based suggestions or priorities given by the owner who seeks the solution. In brief the software defined hardware system helps in processing the raw information to processed data, from where the storing, retrieving, and analysis of data is done using advanced computing tools that are integrated with IoT system. The communication systems help in providing the communication channels and allow protocols between the objects or things or each component of IoT. The best, fast, reliable, and secure convergence of the information technology and communication technology will only happen when an effective IoT architecture layer is built. These architecture layers would vary depending up on the requirements and tasks to handle. However, different researchers have proposed different architectures which are as follows. This section gives the overview of widely agreed and accepted architecture of IoT.

4.1. Three Layer Architecture

Three-layer architecture shown in Fig. 4. is one of the foremost and basic IoT architectures introduced. It is most convenient and easy to implement. The three-layer present in the architecture are perception layer, network layer, and application layer[13-16]. The introduced three layers outlines the functioning of IoT, but still could not give a reliable solution considering the higher facets of IoT. Role and the functioning of each layer present in three-layered IoT architecture is presented in Table 3.

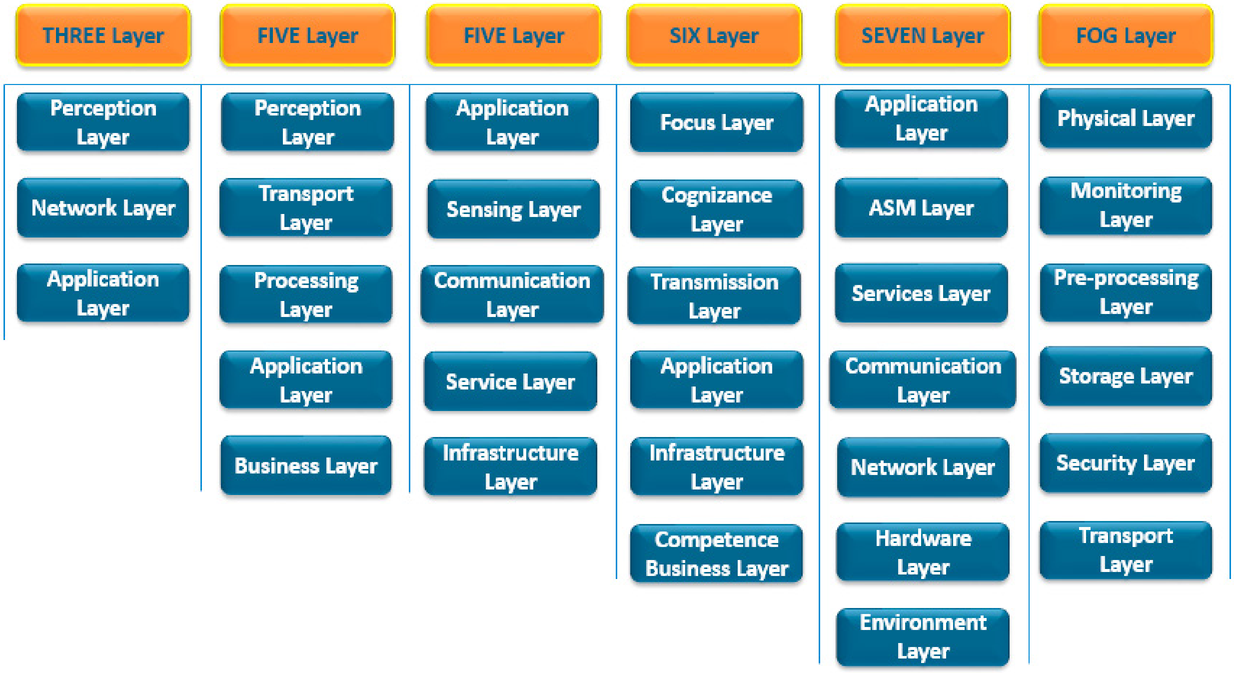

Fig. 4. IoT architecture layers (3-layer, 5-layer, modified 5-layer, 6-layer, 7-layer, FOG)

Table 3. Role and functional features of three-layer IoT architecture

IoT architecture layers	Role and functional features
Perception layer	The features of this layer would be the sensing capability, it collects and gathers the information about the environment where smart objects are available.
Network layer	The feature of the layer is to enable the transmission and processing of the information with internet connectivity of the various devices.
Application layer	Its main feature is to deliver the specific service based on the application type to the user.

4.2. Five Layer Architecture

When the research is focused on finer aspects integrating various technologies and wide parametric application area, the present three-layered architecture is not sufficient, hence researchers have developed the five-layer IoT architecture which is as shown in Fig. 4. The presented five layered architecture is similar with three layered architecture but with extra two layers added[13-17]. Role and the functioning of each layer shown in five layered IoT architecture is presented in Table 4. A modified five layered IoT architecture focusing on wider applications of transport system is shown in Fig. 4. and the roles of each layer is presented in Table 5[18, 19].

4.3. Six Layer Architecture

To make it much easier for understanding and integrating with wider applications (two or more applications together) the IoT architecture layer is modified and a new six-layer IoT architecture is proposed by the researcher by adding focus layer, cognizance layer, and competence business layer to the existing architectures.

Table 4. Role and functional features of five-layer IoT architecture

IoT architecture layers	Role and functional features
Perception layer	The features of this layer would be the sensing capability, it collects and gathers the information about the environment where smart objects are available.
Transport layer	It helps in transferring the information sensed by the sensor available or equipped in the perception layer to the processing layer and vice versa through networks such as wireless, 3G, LAN, Bluetooth, RFID, and NFC.
Processing layer	This layer has special features such as information storage, analytics, and processing the data for allowing the vendors to deliver various kinds of services.
Application layer	Its main feature is to deliver the specific service based on the application type to the user.
Business layer	It manages the entire IoT system where all applications will be managed, especially the business and profit models in a user-friendly way with privacy.

Table 5. Role and functional features of modified five-layer IoT architecture

IoT architecture layers	Role and functional features
Application layer	Collects the information about the various tasks that are to be done as per the client's requirements
Sensing layer	This layer allows an interaction between the application layer and sensing layer by means sensor elements and electronic devices.
Communication layer	Its acts as Information Bridge that helps in the providing a communication link between sensing and service layers for the data transmission.
Service layer	This layer helps in performing the activities that required by the client.
Infrastructure layer	This layer creates the service-oriented technologies like GIS mapping, cloud computing, bid data, cognitive computing storage facility.

This new six-layer architecture allows the IoT system to focus on multiple subject areas and analyzing their implications on the business value in the competent world[20]. Fig. 4. shows architecture of the IoT and their role and features are presented in Table 6.

Table 6. Role and functional features of six-layer IoT architecture

IoT architecture layers	Role and functional features
Focus layer	This layer helps in identifying the nodes considering the multi aspects of the systems that is under study.
Cognizance layer	It is about the sensing capability or the information collection from the objects that focused in the focus layer. Here sensors, actuators, and data monitoring systems are equipped which allows to sense the information.
Transmission layer	Its main feature is to transmit the sensed data from the cognizance layer.
Application layer	This has a special feature of collecting and categorizing the information and as per the requirement in the application zone.
Infrastructure layer	This layer creates the service-oriented technologies like GIS mapping, cloud computing, bid data, cognitive computing storage facility.
Competence business layer	This layer allows the assessment of the proposed IoT system in terms of business network analyzing especially the business and profit models in a user-friendly way with privacy.

4.4. Seven Layer Architecture

Seven-layer architecture is proposed by the researcher by taking considerations of local surrounding environment near to the devices, sensing objects etc.[21] is shown in Fig. 4, and elaborated in Table 7. This new improved architecture allows the user to consider various factors that affects the sensing capabilities of sensors or actuators.

4.5. Cloud and Fog Based Architecture Layers

Cloud computing is more flexible and scalable techniques which allows various services for an IoT systems. These services include information storage options, software tools and analytics, suitable platform, and core infrastructure for the development. With cloud facility, user can have the visualization, machine learning, data analytics options for wider sets of information. Cloud based architecture became popular in IoT systems due to the equivocal nature of the information sensed and produced in the form of data by an IoT devices. In most of the IoT architectures, a centralized control over the data is done using the cloud-based data processing systems, see in Fig. 5. This allowed the IoT system to have a cloud centric architecture making the cloud to be in between the applications and network of things. Here, the central part is cloud, applications were places above to cloud and network of things were placed just below the cloud[16, 22].

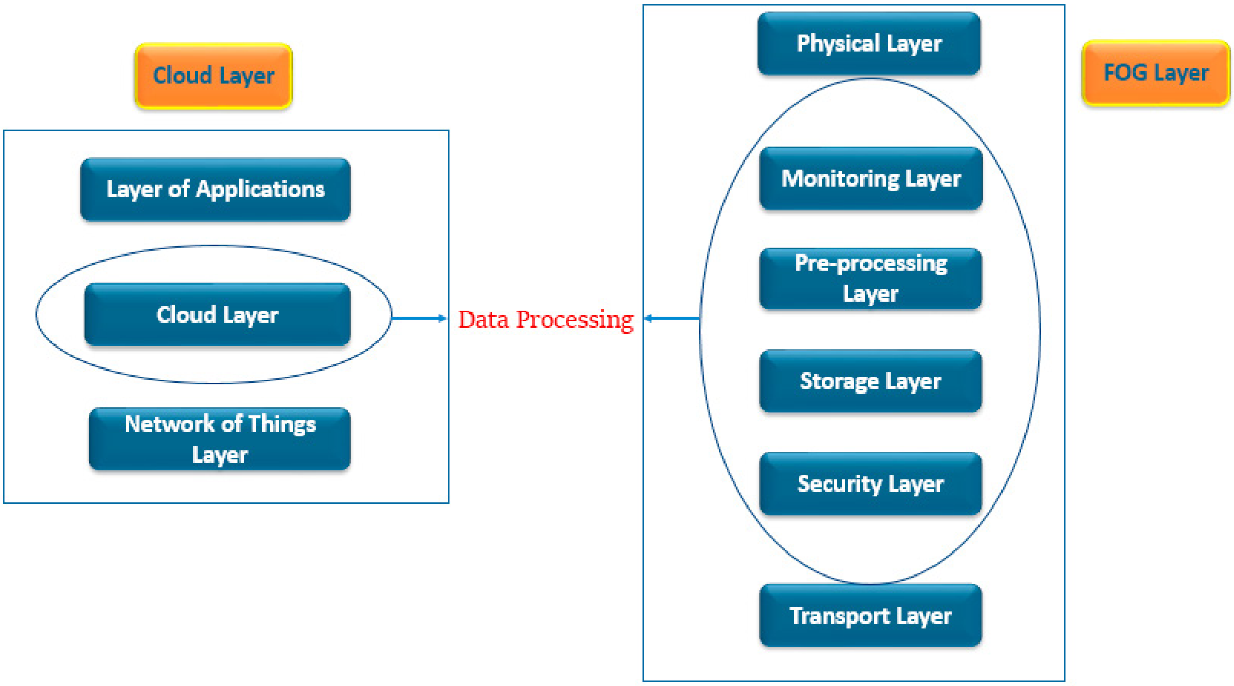

Fig. 5. Data processing in cloud and fog-based architectures of IoT.

In fog computing, the data processing in done in quite different way than to the cloud computing. In fog computing, a fragment of the data analytics is carried out at the sensors, and gateway networks, see in Fig. 5. Unlike other architecture layers of IoT, fog architecture is also represented in terms of layers, see Fig. 4. Fog architecture has six-layered approach, these include physical layer, monitoring layer, pre-processing layer, storage layer, security layer, and transport layer. Here, physical is the one where things need to be analyzed, hence the monitoring and pre-processing layers comes after the physical layer or the at the edge of network of gateways. Here, monitoring layer, performs the monitoring aspects like available resources, required services by the clients, and various responses. From these, the pre-processing layer of fog architecture helps in analyzing the data by doing filtration. Next is the data is sent to the storage layers, where it is stored in different format as required and distributed across as per the need with suitable protocols. Security layer helps in offering privacy status to the data flow. When compared to the cloud architecture fog architecture is quite advanced[16, 23-26].

Table 7. Role and functional features of seven-layer IoT architecture

IoT architecture layers	Role and functional features
Application layer	Collects the information about the various tasks that are to be done as per the client's requirements
Application support and management layer	This layer allows to have complete managerial control, security over the IoT system.
Services layer	This layer helps in performing the activities that required by the client.
Communication layer	Its acts as Information Bridge that helps in the providing a communication link between sensing and service layers for the data transmission.
Network layer	The feature of the layer is to enable the transmission and processing of the information with internet connectivity of the various devices.
Hardware layer	This layer enables to integrate all the hardware components required for the implementation of IoT.
Environment layer	This layer allows the possibility to detect the objects or places that are under observation. This has the capability of observing the "physical moving objects, such as humans, cars, to environmental factors such as, temperature, or humidity".

5. Conclusion

This paper summarizes the understandings of IoT building blocks, IoT components interaction, and IoT architecture layers. A brief about the architecture layers proposed by various researcher is dealt in the paper including the cloud and fog-based architectures. From this survey, we understand that, as the number of architecture layer increases, the complexity in the IoT system design, and integration with the practical environment might become difficult. This might lead to many interactions giving more scope for security issues, data mishandling etc. However, this could be eliminated with the use of blockchain technology. This would help the researcher who are working on computing aspects, IoT system implementation for science and engineering applications.

References

[1] Debasis Bandyopadhyay, Jaydip Sen. (2011) "Internet of Things: Applications and Challenges in Technology and Standardization." *Wireless Pers Commun* **58**:49–69, DOI 10.1007/s11277-011-0288-5.

[2] Santucci, G. (2009). "From internet to data to internet of things." In Proceedings of the international conference on future trends of the internet.

[3] P.P. Ray (2016) "A survey on Internet of Things architectures." *Journal of King Saud University - Computer and Information Sciences*, https://doi.org/10.1016/j.jksuci.2016.10.003. (Article in Press)

[4] L. Atzori, A. Iera, G. Morabito (2010) "The internet of things: A survey." Computer Networks **54(15)**:2787–2805.

[5] A. Zanella, N. Bui, A. Castellani, L. Vangelista and M. Zorzi, (2014) "Internet of Things for Smart Cities." *IEEE Internet of Things Journal* **1(1)**:22-32. doi: 10.1109/JIOT.2014.2306328

[6] Nallapaneni Manoj Kumar, Karthik Atluri, Sriteja Palaparthi (2018) "Internet of Things in Photovoltaic Systems," *In Proceedings of IEEE National Power Engineering Conference (NPEC-2018)*, Madurai, Tamil Nadu, India.

[7] L. D. Xu, W. He and S. Li (2014) "Internet of Things in Industries: A Survey," *IEEE Transactions on Industrial Informatics* **10(4)**:2233-2243. doi: 10.1109/TII.2014.2300753

[8] Home Automation & Security, Sharp Node Blog-Latest in IoT, https://sharpnode.com/post/category/sharpnode/

[9] Ahmed Banafa (2017) "IoT and Blockchain Convergence: Benefits and Challenges." https://iot.ieee.org/newsletter/january-2017/iot-and-blockchain-convergence-benefits-and-challenges.html

[10] Celent, Interaction between the three components of internet of things.
https://qph.ec.quoracdn.net/main-qimg-a1db8df2497ec1c595ca93deef7b25ca

[11] Ram Mohan (2015) "The Internet of Things: Solving Security Challenges from the Fringe to the Core." Afilias plc. https://afilias.info/blogs/ram-mohan/internet-things-solving-security-challenges-fringe-core

[12] IOT Interaction between Components, http://en.huevertech.com/cloud/iot.asp

[13] I. Mashal, O. Alsaryrah, T.-Y. Chung, C.-Z. Yang, W.-H. Kuo, and D. P. Agrawal (2015) "Choices for interaction with things on Internet and underlying issues." *Ad Hoc Networks* **28**:68–90.

[14] O. Said and M. Masud (2013) "Towards internet of things: survey and future vision." *International Journal of Computer Networks* **5(1)**:1–17.

[15] M. Wu, T.-J. Lu, F.-Y. Ling, J. Sun, and H.-Y. Du (2010) "Research on the architecture of internet of things." *in Proceedings of the 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE '10)* **5**:484–487, IEEE, Chengdu, China, August 2010.

[16] Pallavi Sethi and Smruti R. Sarangi (2017) "Internet of Things: Architectures, Protocols, and Applications." *Journal of Electrical and Computer Engineering* **2017**:25, Article ID 9324035. doi:10.1155/2017/9324035

[17] R. Khan, S. U. Khan, R. Zaheer, and S. Khan (2012) "Future internet: the internet of things architecture, possible applications and key challenges." *in Proceedings of the 10th International Conference on Frontiers of Information Technology (FIT '12),* pp. 257–260, December.

[18] Nallapaneni Manoj Kumar, Archana Dash (2017) "The Internet of Things: An Opportunity for Transportation and Logistics." *Proceedings of the International Conference on Inventive Computing and Informatics (ICICI 2017),* pp. 194-197, Coimbatore, Tamil Nadu, India

[19] Intel, Solution Blueprint Internet of Things, Building an Intelligent Transportation System with the Internet of Things (IoT) http://www.intel.com/iot.

[20] Nallapaneni Manoj Kumar, Archana Dash, Neeraj Kumar Singh (2018) "Internet of Things (IoT): An Opportunity for Energy-Food-Water Nexus." *2018 1st IEEE International Conference on Power Energy, Environment & Intelligent Control (PEEIC2018)*, 13th and 14th April, GL Bajaj, Greater Noida, India.

[21] Darwish, D. (2015) "Improved Layered Architecture for Internet of Things." *International Journal of Computing Academic Research (IJCAR)*, **4(4)**:214-223.

[22] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami (2013) "Internet of Things (IoT): a vision, architectural elements, and future directions, *Future Generation Computer Systems*." **29(7)**:1645–1660.

[23] F. Bonomi, R. Milito, P. Natarajan, and J. Zhu (2014) "Fog computing: a platform for internet of things and analytics." *in Big Data and Internet of Things: A Road Map for Smart Environments*, pp. 169–186, Springer, Berlin, Germany.

[24] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli (2012) "Fog computing and its role in the internet of things." *in Proceedings of the 1st ACM MCC Workshop on Mobile Cloud Computing,* pp. 13–16.

[25] I. Stojmenovic and S. Wen (2014) "The fog computing paradigm: scenarios and security issues." *in Proceedings of the Federated Conference on Computer Science and Information Systems (FedCSIS '14)*, pp. 1–8, IEEE, Warsaw, Poland, September.

[26] M. Aazam and E.-N. Huh (2014) "Fog computing and smart gateway-based communication for cloud of things." *in Proceedings of the 2nd IEEE International Conference on Future Internet of Things and Cloud (FiCloud '14)*, pp. 464–470, Barcelona, Spain, August.