Edge Intelligence Models for Industrial IoT (IIoT)

B Sathish Babu[1*], N Jayashree[2]

[1]*Dept. of Computer Science and Engineering, R V College of Engineering, Bengaluru*

[2]*Dept. of Computer Science and Engineering, C Byregowda Institute of Technology, Kolar*

Abstract

This paper reports the application of edge computing and edge intelligence in the context of Industrial Internet of Things. The essentials of edge computing, role of edge intelligence and a few models and cases which make use of Industrial Internet of Things environment are presented. The linkages between edge intelligence and its importance in the field of Artificial Intelligence and Machine Learning based solutions infer that the use of edge intelligence not only decreases the time of data processing but also provides data security.

Keywords: *Edge intelligence, Industrial Internet of Things, Edge Computing, Artificial Intelligence, Machine Learning*

1.0 Introduction

Industrial Internet of Things (IIoT) is a domain of machine to machine (M2M) and industrial communication technology. It is an automation application which provides a better picture of manufacturing process and results in efficient and sustainable production [1]. IIoT find opportunities in automation, optimization, intelligent manufacturing, smart controls, on-demand service model and so on. IIoT can be defined as things enabling the operations of an industry in an intelligent way with advanced data analytics for transformational business outcomes. IIoT combines Operational Technology (OT) and Information Technology (IT). IIoT is adopted by industries because of increased productivity and efficacy through smart and remote management.

IIoT is designed for things that are bigger than general IoT devices like smartphones. It connects devices like industrial engines, power-grids, sensor with clouds, etc. over the network [2]. These devices are connected through a software designed for communication which can instantly collect, transfer, and analyze the data. IIoT applications require relatively small throughput per node and connects large number of devices to the Internet at low cost. These devices have limited hardware capabilities and energy resources that results into a greater need for latency, energy efficiency, cost, reliability and security/privacy. IIoT uses fixed infrastructure-based network that are best applicable for communication and coexistence needs [3].

Some of the challenges faced by IIoT include energy efficiency as the devices need to run for a long period of time without battery replacement, real-time

* *Mail address: B Sathish Babu, Professor, Department of Computer Science and Engineering, RV College of Engineering®, Bengaluru – 59, e-mail: bsbabu@rvce.edu.in Ph.: 9844488329*

performance as the applications require an immediate processing of data and interoperability due to a large number of devices that need to coexist.

1.1. Salient features of IIoT

a. Connectivity: connects devices to the Internet with low cost, uses sensors to collect data for faster processes for better efficiency resulting in lesser expenses for a product or service
b. Energy efficiency: adopts Energy harvesting to increase the battery life of the sensors
c. Operational efficiency: uses real-time data from the sensors for the processes such as monitoring to enhance the efficiency and reducing the energy costs as well as human interventions.
d. Improved Productivity: smart factory allows getting real-time task level data which is continuously generated and standardized for performing a detailed analysis of factory performance. The data generated helps supervisors to easily identify the problematic areas to make decisions in order to meet the continuous needs of the production lines.
e. Downtime reduction: all the data obtained can be used to reduce the downtime during maintenance, assets unavailability, and unavailability of human resources within the factory.
f. Maximization of asset utilization: helps in having good control on the equipment and machinery of a business and achieve proficiency through increased efficiency and productivity, reduced costs on operations and increased customer experiences
g. Safety and security: improves safety at the workplace and protects from physical threats with the help of sensors and video cameras used for equipment monitoring.
h. Quality control: the data collected for IIoT helps to automate the process of quality control.

1.2. Edge computing and its implications

Edge computing has gained more attention with its reduced data transmissions, improved service latency, and reduced overhead on cloud computing. It is needed to make real-time decisions independently within milliseconds. Cloud services and IoT devices are relieved from computation with edge computing. It is used in IoT based application because of the following reasons [4]:

a. Latency minimization: Edge computing guarantees timely delivery of services. It can fulfil the QoS requirements of delay-sensitive IoT applications.
b. Network management: Edge computing effectively utilizes network resources. It is the necessary feature for IoT applications.
c. Cost optimization: Deploying optimal number of nodes at proper locations can reduce capital significantly. Deploying edge nodes optimally can minimize the operations costs.

d. Energy management: There is a need to have control over energy management. Applications that use power harvesting guarantees scalability, cost efficiency, and avoid frequent battery replacement.
e. Resource management: Service-level objectives can be met by optimal computational resource management. This is done by resource coordination, resource estimations and efficient workload allocations.
f. Data management: The IoT devices generate a large amount of data which need to be managed efficiently with time. Edge computing requires an efficient data management mechanism.

Applying edge computing in IIoT results in coexistence of several configurations. It consists of edge nodes placed to monitor applications, routers to forward the packets over the network, and interfacing routers between IIoT and the Internet [5]. Edge devices can capture the streaming data to rapidly analyze and process data. It increases the productivity and implementing inferential capabilities for edge devices is difficult [4]. An edge device provides real time data analysis. The latency is reduced when the data is analyzed at the place of data generation. Edge devices minimize the bandwidth requirements and costs as the data is locally analyzed. The local analysis of data also results in an effective decision making.

1.3 Edge Intelligence

Edge intelligence refers to the domain where the edge devices can collect, communicate, generate, and analyze data in near real-time [6]. Some of the edge devices include sensors, navigation systems, autonomous cars and so on. With edge intelligence, data need not be moved. It can be instantly analyzed for decision making without having to transfer it across different locations. It is flexible and efficient in data analyzing. An intelligent edge follows the ease of SQL combined with industry tools to analyze a large volume of data from varying number of devices. The components of edge intelligence are [6]:

i. Connectivity: Intelligent edge device can connect to any network that can generate and exchange data.
ii. Computing: Intelligent edge device needs local computing resources for real time data analysis.
iii. Controllability: Intelligent edge device uses databases to provide intelligent decisions in case of device controls, dynamic changes and action taking in the networks.
iv. Autonomy: Intelligent edge devices have autonomous computing processes capabilities through edge databases and can process independently.

The following features of edge intelligence make it important to implement in IIoT [7]:

i. Supports data exchanges in long distance transmissions. The database management system on edge devices avoids the need for latency, data rate, and bandwidth for data exchanges.

ii. Support unification of security management system which protects from security threats through cyber-security effort.
iii. Organization using edge intelligence must comply with General Data Protection Regulation to support private data. Edge intelligence provides data and identity management at every edge device to process data securely and avoid unauthorized data accesses.
iv. Along with cloud brings together the necessary infrastructure with programming and database management for the data analysis through an application.
v. Provides an effective integration between the connected devices though the database management and also provides services without interruptions.
vi. Reduces the amount of data transferred to the cloud data centers and hence cloud is made available for other tasks. This improves the system's efficiency and reduces the data transfer costs.

1.4. Motivation for Edge Intelligence

With the growth of Internet of Everything, the data generated by the edge increases invariably [8] resulting into high bandwidth requirements. But the current applications require lower latency. Edge computing provided both the requirements through its guaranteed QoS for large volume of data. On the other hand, the Artificial intelligence applications for machine learning are advanced with the latest models, processing capabilities and amounts of data. The applications act as central body for an effective human interaction through the electronic appliances.

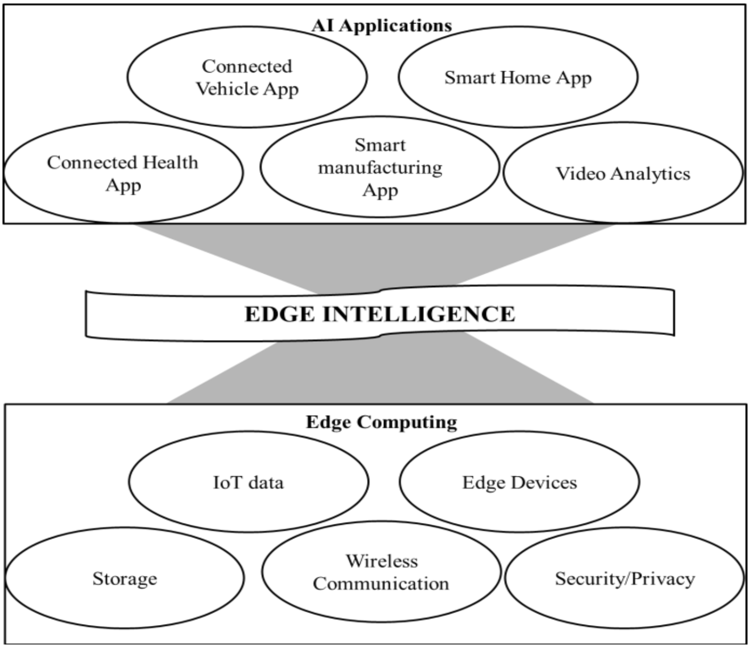

Fig. 1. Motivation to Edge Intelligence

The edge intelligence is hence pushed by the edge computing and is pulled by the artificial intelligence applications as shown in Fig. 1. The edge computing lets artificial intelligence algorithms to run on an edge device. Also the artificial intelligence applications call for run on the edge device. In edge intelligence the artificial intelligence models are optimized for run for optimized machine learning algorithms. In machine intelligence, the data is transferred to the cloud and trained for data analysis. Once the model is trained, the cloud is able to infer based on the edge data and sends response to the edge device. In edge intelligence, the inference is done on the edge device. The data generated by the device acts as input to the model extracted from the cloud. The edge intelligence approach can be upgraded to train the edge and personalize the model at the edge device for a better performance.

1.5. Relevance of Edge Intelligence

Most of the organizations consider the edge intelligence to be a platform to run artificial intelligence algorithms for the data generated on the same device [8]. This requires more resources and better processors at the device. Current edge intelligence approach that deals with the model is trained in cloud data center due to the resource requirements. There is a need to transfer large volumes of data from edge devices to the cloud. It causes a communication overhead and possible threat to privacy. In practical, edge intelligence focuses on optimizing the overall performance in data analysis.

There are five metrics of performance for edge intelligence [7]:

i. *Latency*: it is the total time taken for the inference process. This may be affected due to the resource availability at edge devices or the data transfer techniques.
ii. *Accuracy*: it is the number of correct predictions among the total predictions that represents the overall performance of the model.
iii. *Energy*: the energy efficiency is an important aspect in edge intelligence. This is usually affected by the model used to infer and the resources available at the edge device.
iv. *Privacy*: edge intelligence aims to protect the data privacy at the data source. It depends on the way of analyzing the data.
v. *Communication Overhead*: it depends on the model used to infer the data and the bandwidth requirements.

2.0 Learning Models for Edge Intelligence

Edge intelligence provides a learning process with a heterogeneous environment which combines with a faster computation abilities and achieves a better communication quality with reduced energy consumption. Edge devices avoid the learning process from relying on the cloud and use edge resources for the same. There are models proposed for learning processes based on edge intelligence.

1) *Edge Intelligence in Artificial Intelligence (Complex Edge AI)* [6]: Edge computing is a best model for Artificial Intelligence (AI) applications. Fig. 2 depicts the edge based architecture for AI and facilitates complex edge AI operations scenario. Dispersed Edge and IoT devices generate locality-specific data and share a common knowledge base. The scenario considers AI for decision making. The patterns of data may be similar across the locations where the devices are deployed. To train the base model, on-demand cost efficient public cloud-based machine learning (ML) is used. The data learned are refined by the cloudlets which have access to the local sensors and devices using transfer learning. The cloudlets in turn avoid aggregating the data and produces models the results in low-latency.

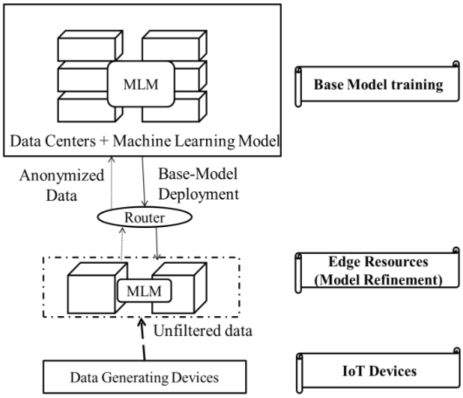

Fig. 2. Edge AI with hierarchical edge architectures

2) *Distributed AI for Intelligence at Edge:* This model is experimented for a home monitoring systems to understand the contribution of edge intelligence. The difference between the cloud-based AI and Edge Inferred AI is as shown in Fig. 3. The edge inferred AI puts less computational load on cloud. It is over 10,000 times lesser than cloud-based AI. The model improves scalability and reduces cost of services. The edge learns the AI model from the local data. The model is then exchanged for faster predictions and information transfer like notifications. The cloud is relieved from the computations of detecting unusual activities. The model trains the cloud for the activity detection. Edge-gateway checks the data quality using the cloud-trained model, and the model is transferred from cloud to the edge gateway. Whereas in cloud-based AI, the cloud-is trained to detect the unusual activities and is also responsible to check the data received from the data transferring devices

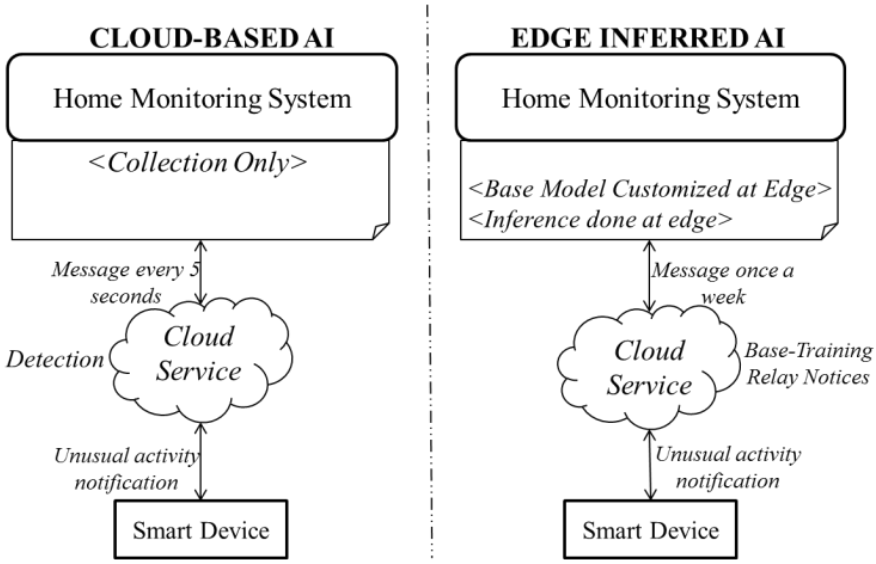

Fig. 3. Comparison of two smart computing models

3) *Edge Intelligence and IoT Sensor Stream System:* Foghorn Model is a method for enabling Edge Intelligence in IoT applications (Fig. 4). The model is triggered by the sensor data which is generated by software in gateway device or an embedded system [9].

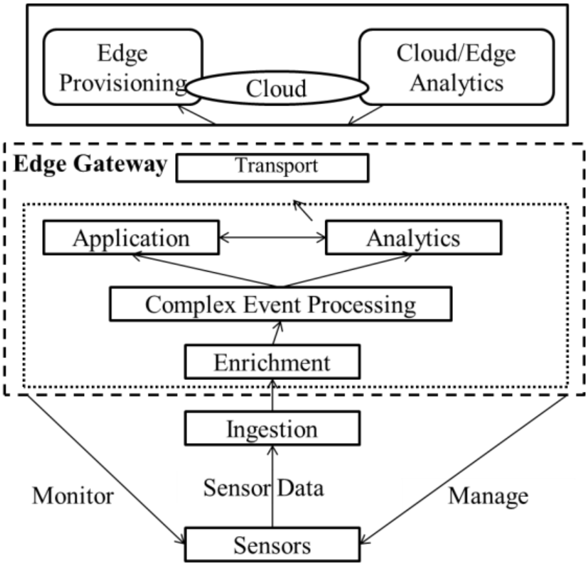

Fig. 4. Edge Intelligence and IoT Sensor Stream System

The layer with the software is connected to a LAN. The layer can access services, applications, and also data processing devices. The layer can match a sensor data with the descriptions of pattern relating a set of patterns of events; automatically identify the events through the continuous execution of expressions; intelligently connecting the services and applications at the edge gateway to link the analytical expressions for the event detection; evaluation and fine tune the model for analytics; and monitoring the status of the software. The gateway also enables to store the raw sensor data and related results in time-based cloud storage.

4) *Hyper-connectivity with Edge Intelligence:*

The model as shown in Fig. 5 represents cloud IoT Edge extending a cloud platform's data processing and machine learning (ML) to the edge devices for processing the data received from the sensors in real-time and make decisions [10]. The model can run on either the smart devices or a desktop with Linux operating systems. There are two components activated during runtime: Edge IoT and Edge ML. The cloud platform is enabled to run ML models on the edge devices. The edge device can store, translate, process, and extract intelligence through the edge devices and interoperates with the cloud platform.

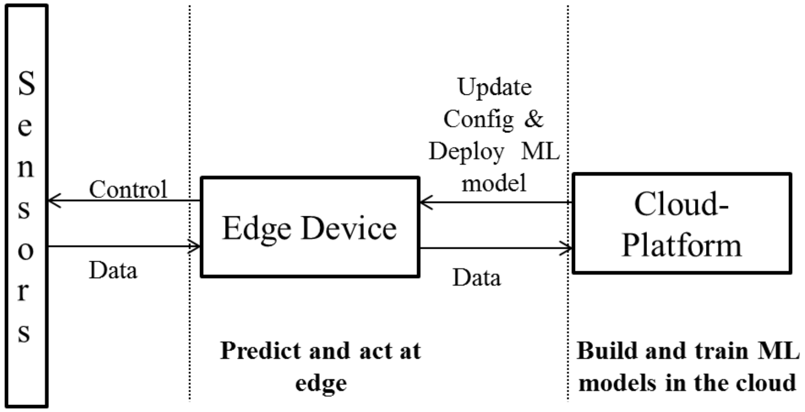

Fig. 5. Edge Intelligence with Cloud-based IoT

5) *Edge Intelligence in IIoT Applications:* IN THIS SECTION, WE PRESENT SOME OF THE EDGE INTELLIGENCE APPROACHES FOR IIOT :

i. *Fog Horn* [2]: It is a leading developer of edge intelligence software for industrial IoT (Fig. 6). The model created for Industrial IoT consists of four major components: machine learning; applications/SDK; local histories and enrichments. A FogHorn manager in this model, manages the data analysis between the four components. The manager implements edge management, edge configurations, edge monitoring, and edge to cloud analytics.

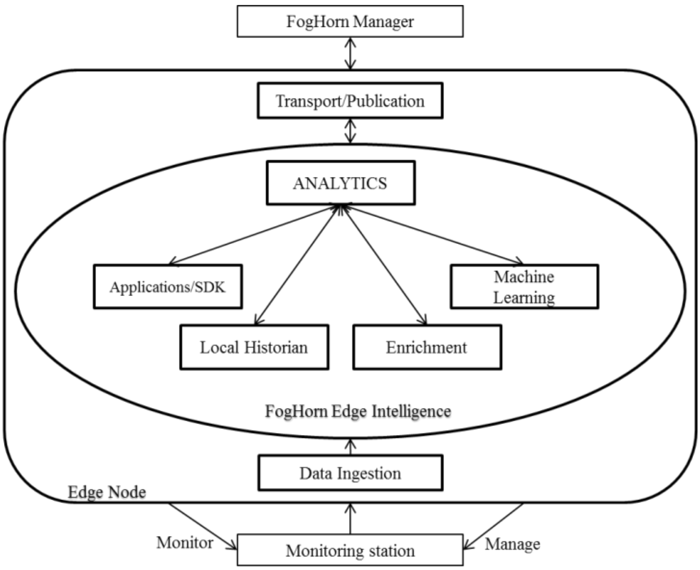

Fig. 6. FogHorn IIoT

Condition monitoring of distribution transformers in an industrial setting [11]: This model demonstrates industrial application of edge intelligence which focuses on condition monitoring of distribution transformers with temperature sensing at surface level (Fig. 7). It contains remote conditioning, monitoring and the maintenance system to accommodate devices that provide a wider functionality than measurement. There are transformers at remote places to transfer the data generated by edge devices. The analytics task is done by the edge device through convergence of information and operation technologies.

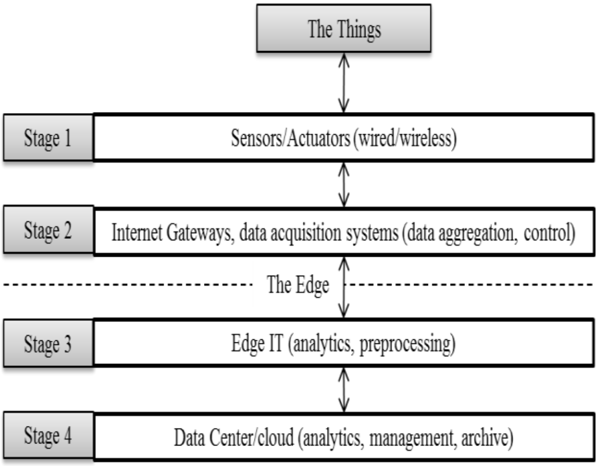

Fig. 7. Conditional Monitoring Model

ii. Blockchain-based Smart Factory [3]: Each entity in the model is a node in IIoT named as either light node or full node (Fig. 8). Light nodes are IoT node that are power constrained and hence do not participate in blockchain sharing. They forward transmissions to the full nodes which are powerful nodes like gateways, servers, etc. the light nodes are implemented based on PyOTA which is a IOTA Python API library.

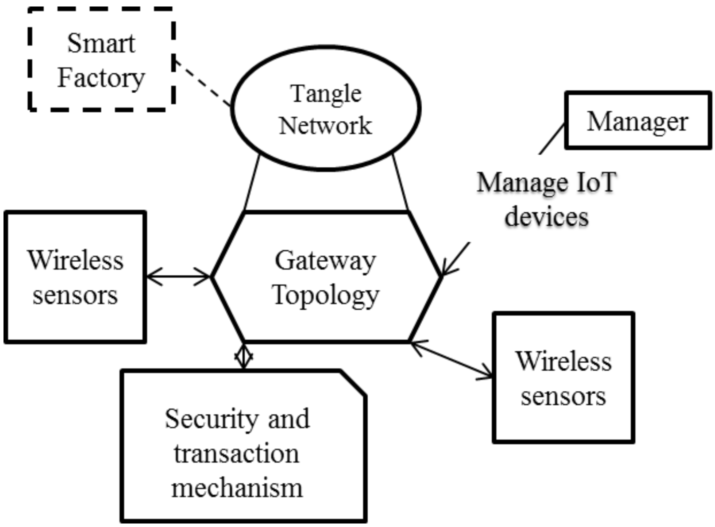

Fig. 8. Blockchain-based IIoT for smart factory

A Full node maintains the blockchain network and broadcast the transactions to the blockchain networks for the completion. They provide a convenient RESTful HTTP interface which receives transactions from light nodes via RPC interface

The model has four components

1) *Wireless sensors*: These are deployed in a smart factory and belong to light nodes. Each sensor generates unique ID for each device and distributes the keys.
2) *Gateways*: These are the full nodes that maintain the network. Gateways receive the request and broadcast them to the blockchain network.
3) *Manager*: It is a full node that manages the IoT devices. The manager has the authorities to publish the list of devices in the network.
4) *Tangle Network*: It is public blockchain network that can be accessed by anyone. It is kept secure and stable by gateways. A PC is used as a gateway/manager to run a full node. Raspberry Pi Model 3B is an IoT device to run light node. A continuous data collection is reported by Raspberry and the status is shown on PC.

iii. HealthIIoT: HealthIIoT (Fig. 9) is a model proposed for healthcare industry to monitor a patient's health [12].

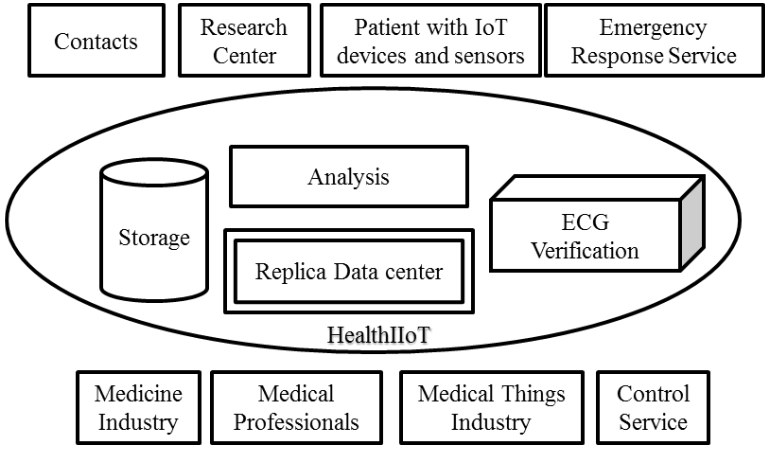

Fig. 9. HealthIIoT Ecosystem

HealthIIoT uses MySQL for as database. The components of HeathIIoT are large number of interconnected machines, IoT devices, sensors, cloud-based computing technologies necessary to collect patient data. The model can transfer the patient information faster to the authorized team of healthcare. Because of cloud-based technology used, the data analysis, storage, data monitoring, and secure transfer to be efficient. The HelthIIoT is a platform for interconnected medical devices which helps to operate on large volumes of data generated from anywhere at any time. The data analysis is done though the e-health records, imaging equipment, sensors, and smart devices. The analysis improves the decisions of the healthcare professionals and enables patients easily manage their personal health. The connected devices and sensors record the patient data and forward it to the cloud-based system through network connections. The cloud validates the data and classifies to redirect to the healthcare professionals for patient care.

iv. Boomerang: It is an automatic inference framework designed for IIoT [13]. Boomrang uses Raspberry Pi as a IIoT device with a desktop PC with 8GB RAM. The bandwidth between IoT device and an edge server is controlled by WonderShaper tool. It works in three phases (Fig. 10):

a) Install: all the devices and edge server gets the Deep Neural Network (DNN) model during installation. The model creates a prediction model and right-sizing model for each layer in the network. The DNN model is trained to obtain accurate predictions.

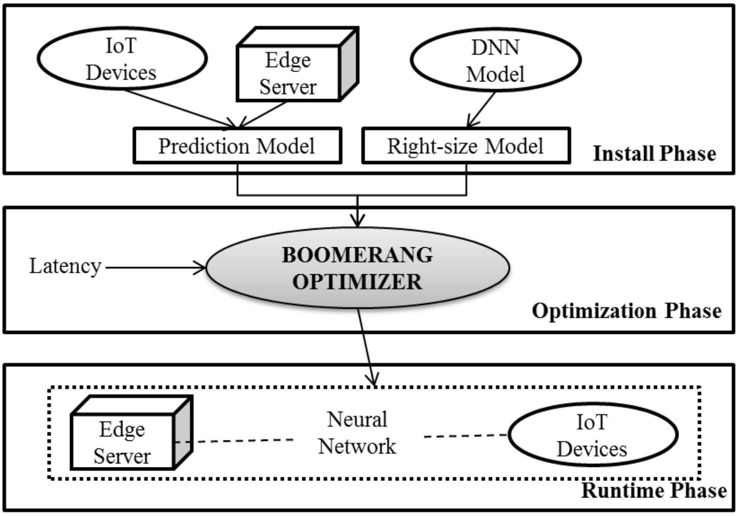

Fig. 10. Workflow of Boomerang

b) Optimization: The model generated in the first step is fed to the Boomerang optimizer along with the latency requirements to optimize the DNN to obtain maximum accuracy.

c) Runtime: the computations are shared between the edge server and other devices. The first half of the computation is done by the edge server and the remaining is processed by other devices. Boomerang sets higher bandwidths and hence improves accuracy through efficiency in large size computations. It also satisfies the latency requirements. In IIoT applications Boomerang can attain higher efficiency due to the lower latencies.

3.0 Conclusions

IIoT driven applications are emerging domain in the data analytics. Applying IIoT to artificial intelligence and edge computing enables efficient processing of data either to make decisions or to transfer to the other devices in the network. With the application of edge devices, that are equipped to locally process data and hence being an intelligent edge device, reduces the time required to process the data. The security approaches applied in the edge computing results into secure transfer of data from one device to another.

References

1. Emiliano Sisinni, Abusayeed Saifullah, Song Han, Ulf Jennehag, Mikael Gidlund, Industrial Internet of Things: Challenges, Opportunities, and Directions, *IEEE Transactions on Industrial Informatics*, 14(11), 4724-4734. 2018

2. Zhi Zhou, Xu Chen, En Li, Liekang Zeng, Ke Luo, Junshan Zhang, Edge Intelligence: Paving the Last Mile of Artificial Intelligence with Edge Computing, 1-24, 2019

3. Junqin Huang, Linghe Kong, Guihai Chen, Min-You Wu, Xue Liu, Peng Zeng, Towards Secure Industrial IoT: Blockchain System with Credit-Based, *Consensus Mechanism*, 15(6), 3680-3689, 2019
4. Najmul Hassan, Saira Gillani, Ejaz Ahmed, Ibrar Yaqoob, Muhammad Imran, The Role of Edge Computing in Internet of Things, *IEEE Communications Magazine*, 56(11), 110-115, 2018
5. Sandro Pinto, Tiago Gomes, Jorge Pereira, Jorge Cabral, Adriano Tavares, IIoTEED: An Enhanced, Trusted Execution Environment for Industrial IoT Edge Devices, *IEEE Internet Computing*, 21(1), 40-47, 2017
6. Thomas Rausch, Schahram Dustdar, Edge Intelligence: The Convergence of Humans, Things, and AI, IEEE International Conference on Cloud Engineering (IC2E'19), 1-11, 2019
7. Zhi Zhou, Xu Chen, En Li, Liekang Zeng, Ke Luo, and Junshan Zhang, Edge Intelligence: Paving the Last Mile of Artificial Intelligence with Edge Computing, *Conference Paper*, 107(8), 1738-1762, 2019
8. Xingzhou Zhang, Yifan Wang, Sidi Lu, Liangkai Liu, Lanyu Xu, Weisong Shi, OpenEI: An Open Framework for Edge Intelligence, *ICDCS 2019 Conderrence*, 2019
9. S K M Malladi, T M Ravi, M K Reddy, K Raghavendra, Edge Intelligence Platform and Internet of Things Sensor Stream System, *Patent Application Publication WO2017035536A1*, 2016,
10. Ovidiu Vermesan, Markus EisenHauer, Martin Serrano, The Next Generation Internet of Things- Hyperconnectivity and Embedded Intelligence at the Edge, *River Publishers Series in Communication*, 20-102, 2018
11. Hugh Boyes, Bil Hallaq, Joe Cunningham, and Tim Watson, The industrial internet of things (IIoT): An analysis framework, *Computers in Industry*, 101, 1-12, 2018
12. M Shamim Hossain, Ghulam Muhammad, Cloud-assisted Industrial Internet of Things (IIoT) –Enabled framework for health monitoring, *Computer Networks*, 101, 192-202, 2016
13. Liekang Zeng, En Li, Zhi Zhou, Xu Chen, Boomerang: On-Demand Cooperative Deep Neural Network Inference for Edge Intelligence on the Industrial Internet of Things, *IEEE*, 33(5), 96-103, 2019