Lappeenranta University of Technology
School of Engineering Science
Erasmus Mundus Master’s Programme in PERvasive Computing and COMmunication for Sustainable Development (PERCCOM)

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PERFORMANCE EVALUATION OF IoT PLATFORMS IN GREEN ICT APPLICATIONS

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ABSTRACT

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Performance Evaluation of IoT Platforms in Green ICT Applications

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63 Pages, 24 Figures, 4 Tables, 2 Appendices

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With the advent of Internet of Things (IoT), its deployment and applications has grown exponentially in the past decade. This growth has had led scientists and stakeholders to the prediction that about 30 billion of things (IoT) will be connected by 2020 in diverse applications such as transport, healthcare, utility, education and home automation. Large data streams generated by sensors; be it data acquisition, storage, or processing, derived the development of cloud-based middleware (or otherwise known as IoT Platform) for IoT. To date, hundreds of IoT platforms fluxing the market (both open-source and commercial) with various complexities, pricing and services. In this thesis, we proposed a IoT Platform Benchmarking Methodology comprised of four different evaluations namely; Technical, Usability, Sustainability and Market Competency. We discussed in detail Technical Evaluation based on TPC-IoT benchmarking to evaluate the performance of any IoT platform. The main objective of this research is to provide insight into key parameters in each layer of the platform affecting the overall performance. A preliminary evaluation of data ingestion of open-source IoT platform will be presented based on benchmarking methodology (TPC-IoT).

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LIST OF SYMBOLS AND ABBREVIATIONS

BW	Bandwidth
CoAP	Constrained Application Protocol
CPU	Central Processing Unit
EU	European Union
HTTPs	Hypertext Transfer Protocol(secure)
IT	Information Technology
IETF	Internet Engineering Task Force
IP	Internet Protocol
IoT	Internet of Things
LAN	Local Area Network
M2M	Machine to Machine
MQTT	Message Queuing Telemetry Transport
NGSI	Next Generation Services Interface
PaaS	Platform as a Service
REST	Representational State Transfer
RFID	Radio Frequency IDentification
SaaS	Software as a Service
SD	Sustainable Development
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
WSN	Wireless Sensors Network

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1 INTRODUCTION

The pace of technology evolved in the last decades observe the shifting of trends from third industrial revolution to a new paradigm [2]. Scientists, cloud vendors, manufacturers, network providers and researchers proposed that the number of connected things over internet (IoT) will grow exponentially to a figure of tens of billions, in the next decade [3] [4] [5].

Development in ubiquitous computing, adoption of wireless sensors networks and cloud technology is developing a paradigm of IoT-Internet of things [6]. The IoT is a complex network of interconnected things and people – all of which share and collect data about the way they are used and about the environment around them. It is considered as the future estimation of the Internet of Things considering machine-to-machine (M2M) learning [7] with or least human intervention to allow exchange of data by secure and autonomous connection between real world devices and applications [8].

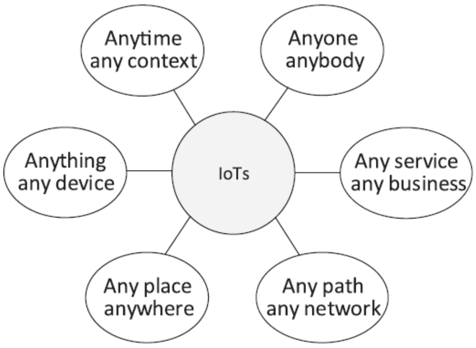


Fig. 1. Scope of Internet of Things. [8]

Deployment of IoT system and its components can be composed of three major layers. Data Ingestion or sensing, Data Storage & Processing and upper layer can be named as Control and Application layer where users can deploy applications depending upon the scenario. Sensing layer is responsible for gathering data from sensors and APIs or other networks and actuators are also deployed in this layer. Actuators and sensor are usually energy and computing constraints. Suitable storage and compute platform is required for the processing and storage of data gathered from the sensing layer. Device management also plays an important role. Factors need to be consider are scalability, security and availability of the cloud [9]. That's why it is proposed to deploy IoT components in a cloud-based computing platform which can provide functionalities discussed earlier. Typical infrastructure of an IoT Platform can be sketch into three layers which will be discussed in detailed in chapter 2.

1.1 Background

According to [10] the human population in 2008 has surpassed the settlement in urban areas than non-urbans. And as the rate of growth, by 2030 about 73% of the global population is expected to live in urban areas. Policy makers, governments, technology providers, companies, international organizations, and civil society across the globe have serious consideration over the current infrastructure and its limitations for the future challengesto transform the potential of rapid urbanization is an opportunity to encourage development and prosperity in societies [9]. However, ICT enabled disruptive innovations and research on cloud computing, automation & robotics, simulation, AI and IoT and their applications that make able to regulate and optimize their environment and affects all walks of life for instance, smart transportation, smart healthcare system, smart education, governance combinedly referred as "smart cities" [11].

The concept of smart cities has been in the technology buzz recently and is defined by European Commission [12] as *"In a smart city environment, various systems based on smart technologies are interconnected to provide required services (health, utilities, transportation, government, homes and buildings) which could be seen as an application of ubiquitous services, aims to improve the quality of life in the city by making it easier and more convenient for the residents to find information of interest."*

In the smart city paradigm, the IoT will be the main player to monitor and regulate resources based on constant data collection from sensors and devices and will be processed using IoT Platforms to take value and make decisions. Gartner defines an IoT platform *as "a software suite or a PaaS cloud offering that monitors, and may manage and control, various types of endpoints, often via applications end users build on the platform. It facilitates operations involving IoT endpoints and integration with enterprise resources"*

[13]. It can be implemented on any infrastructure, healthcare, let say for betterment of citizens and environment. One of the application can be environment or air-quality monitoring so that measures can be taken for any area affected by air pollution. For example, transportation system can be optimized based on vehicle monitoring and congestions can be controlled and infrastructure (road, subways, tramways) [14].

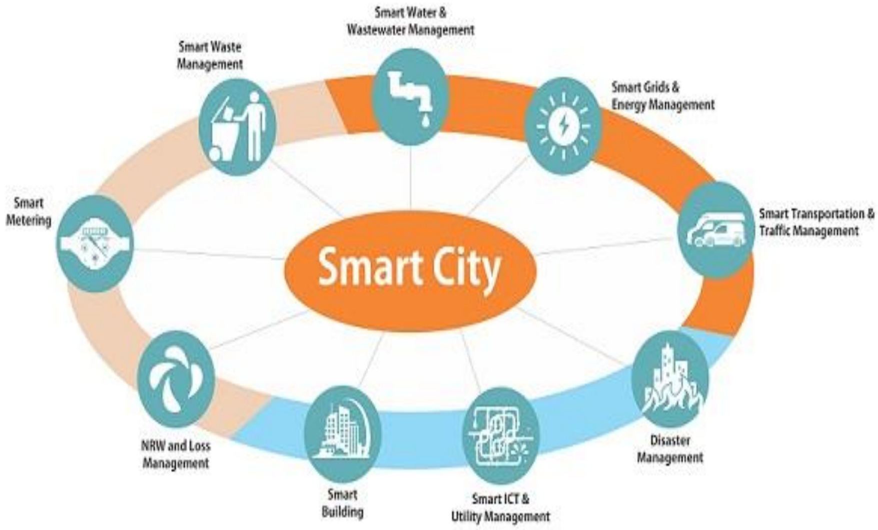


Fig. 2. Smart City Example. [14]

Deployment of IoT system and its components can be composed of three major layers. Data Ingestion or sensing, Data Storage & Processing and upper layer can be named as Control and Application layer where users can deploy applications depending upon the scenario. Sensing layer is responsible for gathering data from sensors and APIs or other networks and actuators are also deployed in this layer. Actuators and sensor are usually energy and computing constraints. Suitable storage and compute platform is required for the processing and storage of data gathered from the sensing layer. Device management also plays an important role. Factors need to be consider are scalability, security and availability of the cloud [15]. That’s why it is proposed to deploy IoT components in a cloud computing platform which can provide functionalities discussed earlier. Typical infrastructure of an IoT Platform can be sketch into three layers as shown in below figure [7].

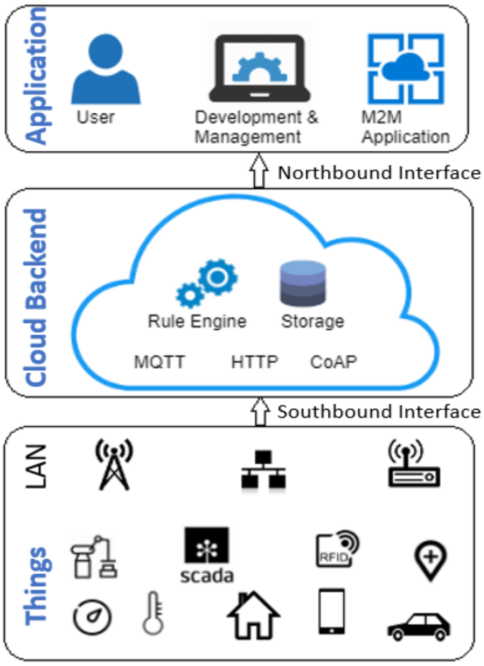


Fig. 3. Cloud Based IoT Architecture. [7]

1.2 Motivatoin

According to Gartner reports there will be 50b of devices connected by 2030 and as discussed above that it will populate the smart city and generate thousands of bits of data. As said in [8] the cloud-based platforms are needed to store, process and manage data. These platforms are known as IoT Platforms. The capabilities of a typical IoT platform includes data storage, sensor or objects management, data handling and processing. It also ensures security, event processing, interfeace for administartion, elements for application development, users and developers. Existing platforms of Internet of Things seriously vary in pricing formula, perfromance, limitation and functionality [13].

This thesis aims to target the performance evaluation on the basis of two factors load scalability of a OpenIoT platform for air quality monitoring application (where hundreds of sensors are updating data continuously). Performance is based on the matrix of latency, throughput and resource utilization of OpenIoT.

This cloud-based system needs to be scalable to handle such requests. For our experimentation we will take approaches, horizontal scaling and vertical scaling of resources.

1.3 Research Questions & Aim

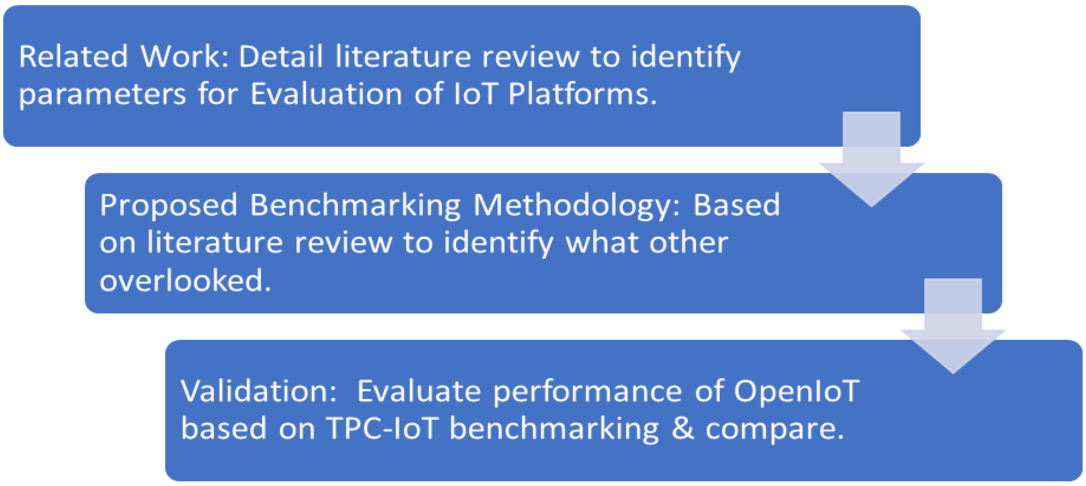
To propose a benchmarking methodology for performance evaluation of IoT Platforms. Validate benchmarking by comparing performance (data ingestion and scalability) of two platforms subjected to an application (use case).

Following research questions has been raised to achieve the afore mentioned aim:

1. What are the factors involved in Benchmarking for Performance Evaluation of an IoT Platform?
2. What is Performance of OpenIoT based on TPC-IoT benchmarking? (Scalability) as compared to another open IoT platform?
3. Suitable candidate for use case (air quality monitoring -IoT application).

1.4 Methodology

In this research we followed Qualitative research to propose a benchmarking methodology for performance evaluation of IoT Platforms and then Quantitative Analysis will be provided for validation based on use case.



1.5 Sustainability

Sustainability concern become visible in society in late 1970s, with the emegre of environmental aspects. In the beginning it was define on the basis of three pillar model, namely environment, social and economy. Last decade, Rachel Carson wrote a book titled The Silent Spring which had shed light on climate change and global warming related issues and effects to the public, making his point related to the topic of the environment rise. Sustainability gained prominance recent years since many scientists felt environmenal changes like global warming etc. And their effects on economies and socities [16].

The term sustainability or equally used term Sustainable Develeompment is defines as ”a development that meets the need of the present withour compromising the ability ofthe future generations to meet their own needs” [17]. As discussed above there are three major aspects of Sustainable Development:

Economic Pillar: This pillar focus on the economical and financial benefits.
Environment Pillar: This domain emphasize on the natural resources and affects of development on environment for instance carbon footprint.
Social Pillar: Social stability and evolution are main features of this factor of the sustainable development.

As part of Erasmus PERCCOM program this thesis emphasize on the sustainability aspects based on Becker’s model [1] as shown in fig. 4. There are five dimensions namely, Economical, Technical, Social, Individual and Environmental divided into three categories Immediate, Enabling and Strucutural affects of each dimension. This thesis focus on Technical, Economic and Environmtal dimensions with Immediate Effects. Performance Benchmarking of IoT platform will enable stackholders to chose the right platform for available applciation hence its improve the resource utilisation and also enables stakeholders to balance the environmental effects i.e. carbon footprint of the solutions. In enabling effect, it will directly targets the social, individual and economic dimensions as details are mentined in the fig. 4 below.

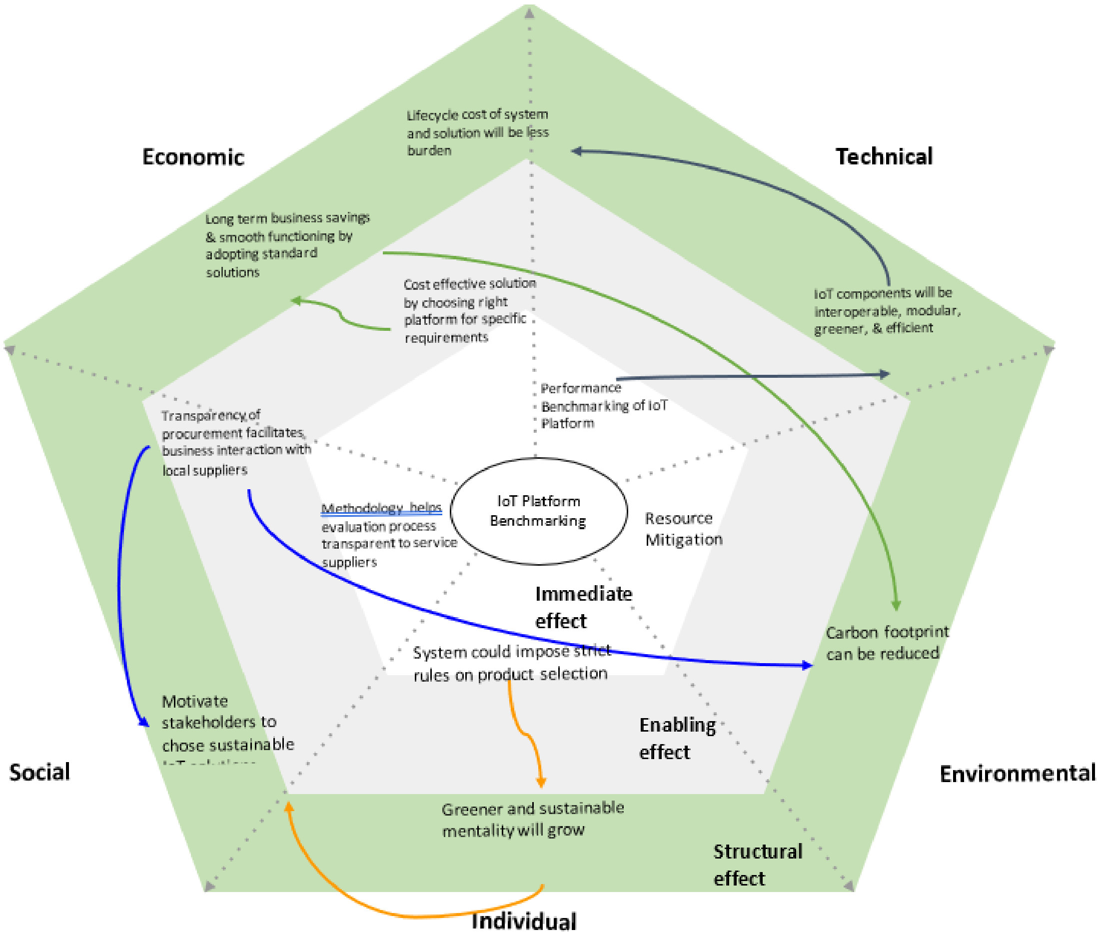


Fig. 4. Becker's Sustainability Analysis

1.6 Thesis Outline

Thesis organization is constructed as following chapters with description.

Chapter 1 provides Introduction to the thesis topic and motivation. It also shed light to discuss the research problem and aim of this project.

Chapter 2 presents the literature review and provides insight into the infrastructure, limitation and challenges of the IoT Platforms in the market. It will also shed light on OpenIoT and KAA opensource IoT platform and study case, air quality monitoring.

Chapter 3 describes the main research methodology in terms of proposing the Benchmarking criteria for Internet of Things Platform performance.

Chapter 4 presents the experimentation setup, results and evaluation of the results and compare with the previous work.

Chapter 5 will conclude thesis with Conclusion and future work.

2 BACKGROUND AND RELATED WORKS

In this chapter we will describes the literature review of the topic and technical background in the domain of IoT Platforms, Internet of Things and covers topics related to open source IoT platforms namely OpenIoT and KAA.

2.1 The Internet of Things

The term IoT (nternet of Things) was first introduced in 1999 by the Kevin Ashton in chain supply management, it was an idea of ubiqitous sensing so that all the things or objects would be connected via internet and having some compuational power. The idea of Internet of Things evovled over the decades with the advent in sensor technology, system on chips and cheap acces of internet. Its a vision where day to day life things or objects are inter-connected to sense their environment, pull data, communicate with each other without any human intervention, take smart decisions and affect the envirnement accordingly [18].

By the time with development and the research in the vision of Internet of Things brought its applications in all walks of life, for instance, transportation, healthcare, agriculture you name it. This rapid growth appeared due to evolving sensor technology, computation and cloud computing [19]. However, there are still some challenges to be addressed and questions to be answered in terms of standardization, cross-platform interfaces, security and communication protocols where lots of players are eveolving in the market.

Although this vision has its implications and still in its infacy but research and market reports expect that over all annual impact by IoT would have a revenue of 2-6 trillion US dollars by 2025. Machine to Machine traffic will comprise of almost 50% of the internet traffic and 20-30 billion of smart devices or objects will be connected by the next decade. Ofcourse, the range of applications and the benefits society will reap, target to improve the over all quality of life. Be it healthcare, education, agriculture or smart city life [18].

The concept of Internet of Things will also target the sustainability aspects. It has good potential to target many sectors to increase the efficiency of systems into the economy by optimizing the processes of business models and industries. Research shows that it can eradicate 15% of carbon emissions gobaly using the smart technologies by 2020 [20].This chapter will cover the fundamental architectural elements of Internet iof Things. Later, we elaborate the middleware and frameworks in the concept of Internet of Things. Lastly, Two of the open source IoT platforms, OpenIoT and KAA and their functionality will be discussed. Their architecture, specifications and componencts to build applications.

2.2 Internet of Things Architecture

According to [7-8], IoT architecture can be broadly divided into 3 main elements or layers:

1. Hardware: sensing devices, communication hardware, actuators.
2. Middleware: compute and storage resources for data handling.
3. Presentation: interpretation and visualization tools.

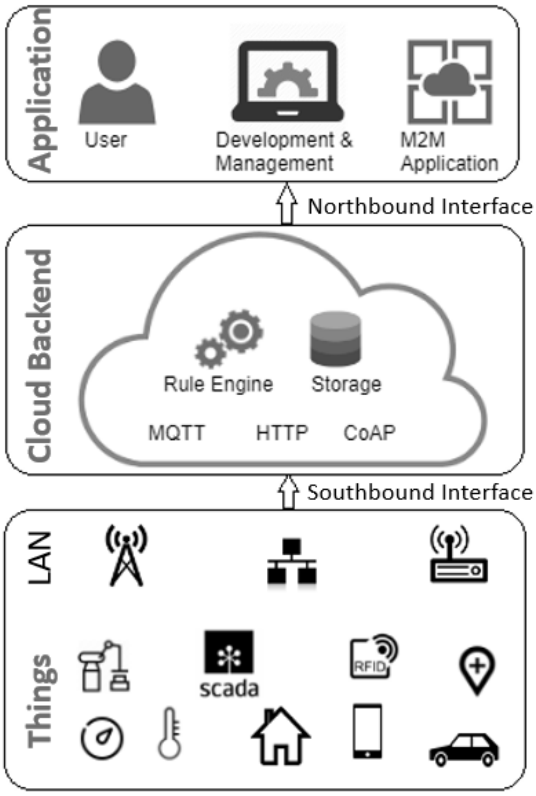


Fig. 5. Cloud Based IoT Architecture. [7]

Currently the Internet of Things is hot debate amongst researchers and stakeholders, and characterized by various standards, initiatives and technology enablers. Therefore interoperability, security and standardization are one of the challenges yet to addressed [21]. Various applications have been developed with their customized architecture and protocols in the vertical domain in field of logistic and smart transportation system. However, initiatives are taken to converge standards and protocols for instance OMA LWM2M and interoperability initiatives like INTER-IoT [22]. Key enablers like IoT-EPI projects [23] like bIoTope, AGILE and INTER-IoT are efforts to bring together different players, implementations which can be re-usable across different application domains.

The next crucial element or component in Internet of Things architecture, is define and characterized in many surveys by Al-Fuqaha and others in [5-10] and by Gubi et in [18] is known as ‘sensing’. It is the baseline of the Internet of Things architecture, which is also known as ‘things’, includes the sensors which are responsible to measures any physical phenomenon, actuators trigger any action in response back from the system. Hundreds of millions of ‘things’ or devices will be connected to become an element of Internet of Things, and particular addressing schemes and identification tags are required due to large scale of their deployments. These things need to be ‘connected’ so communication elements are also required to connect heterogenous devices. Wireless Sensor Networks (WSNs), Radio Frequency Identification (RFID) and IEEE protocols for instance Wi-fi (802.11), Bluetooth (802.15) and IETF Personal Area Networks (6LoWPAN) are some of the widely used technologies for connectivity [18].

Data acquisition and storage is the next step in the characterization of Internet of Things paradigm. Processing and analytics are needed to be done from raw data acquired from sensors. Data with context or knowledge is produced through processing, machine learning algorithms or analytics for smart applications. This process is usually part of cloud layer of the architecture as shown earlier in figure 5 and discussed in [7] as domestic solutions are not feasible for large data sets.

Al-Fuqaha et al [7] elaborate classification of services into Ubiquitous Services, Identity-related Services, Collaboration Aware Services and Information-Aggregation services.

According to the classification mentioned, the functionality of Identity Service is to distinguish the deployed devices. Collaborative Aware Services retrieve data from Information Aggregation Services to take decisions to implement in the application which makes it smart. Information and Aggregation Services are used to enable the aquisition and summarize data from sensors. [7]. The sensing layer is responsible to manage physical objects to sense the phenomenon in surrounding environment, whereas the network layer is the infrastructure that is responsible for communication between these things. Moreover, the service layer enables the services utilized by user and applications. Finally, the interaction method by users and application is defined by the Interface Layer.

2.3 IoT Platforms or Middleware

IoT platform otherwise middleware is responsible for communication amongst heterogeneous devices, by providing a connectivity layer as shown earlier in fig. 5 that is used by physical layer devices and by the application layers to provide services in the Internet of Things [23]. Middleware platform function as bridge to supports Application Program Interfaces (APIs), protocols and services, to support the environment that enables devices to communicate each otehr, applications and networks that are required to communicate in the Internet of Things [24]. The middleware providers market is evolving rapidly. There are lots of challenges arising for instance, scalability, interoperability and security which are also suggested as one of the criteria for evaluation of platforms. Existing solutions addressed different technical solutions that may include pub/sub model, context-awareness and service oriented architectures [25]. Furthermore, there are commercial and open source middleware projects for real world application deployments available in the market recently. These projects are not just for research prototypes but also target the consumer market to be adopted. Middleware and technology ecosystems are developed by these initiatives, with the direct or indirect support of giant companies and non-commercial organizations, including government bodies, Industrial manufecturers standards organizations. For example, the Linux Foundation’s IoTivity, Alphabet’s (Google) Thread, and the Lightweight M2MT by Open Mobile Alliance [26]. Opensource examples may include the European Initiatives like OpenIoT middleware, and the European initiative OpenIoT which is cruicial piece to play a role in smart cities.

2.4 OpenIoT Platform

The OpenIoT – The Opensurce Internet of Things is joint venture of research partners to provide an opensource utility for large scale intelligent IoT deployments based on cloud computing model. OpenIoT is a middleware infrastructure that supports integrating Internet of Things solutions by provied following services [26]:

1. Providing a physical platform for collecting and processing data from any type of sensors, including virtual sensors, physical devices or APIs. It has X-GSN (Extended Global Sensor Networks) module which enables integration of any kind of device, object which can provide observation of physical ohenomeno.

2. It semantatically annotates sensor data with specific to the standards of W3C Semantic Sensor Networks (SSN)

3. After acquiring data from the sensors its responsible for streaming data to cloud computing layer for storage and analytics.

4. Dynamically querying/discovering sensors and their data.

5. Make sure to deliver IoT services that are converging from different resources.

6. Visulaisation layer help for data visualization based on appropriate techniques (maps, grapgh or charts etc).

7. Optimization of resources within the OpenIoT infrastructure and cloud computing module.

OpenIoT is updated of cloud computing, which is responsible to enable IoT based capabilities and increasingly important resources. In particular, OpenIoT enables the means for managing and formulating the ecosystem comprising IoT resources, enables on demand utility or IoT servcie for example the sensing-as-a-service.

OpenIoT is spreaded to a wide range of technologies and interrelated scientific areas spanning [27]:

- Middleware, i.e. for sensors integration and wireless sensor networks.
- Ontologies, annotation and models for enabling internet-connected devices, with semantically linked data techniques.
- Utility based Cloud computing, including privacy and security schemes.

2.4.1 Architecture

In OpenIoT the X-GSN (extended global sensor network) module is responsible for the integration of sensors, registration and data-acquisition from sensors. It is also responsible for semantically annotating the metadata and sensor data [26].

Virtual sensor represents any abstract entity (physical device) and it needs to register within LSM (Linked Sensor Middleware). RDF (triple data entity composed of subject-predicate-object database).

The OpenLink developed Virtuoso (Virtuos Universal Server) serves as the core database of the OpenIoT platform. It is a database engine which has hybrid features of ORDMBS, a virtual database, traditional XML, web-application server, Resource Description Framework hence, provides different services in a single database system [27].

Mostly Internet of Things platforms proposed these storage types: relational data base, in memory, Resource Description framework, column-oriented. Blob storage are usually performed using OpenStack Swift. RabbitMQ and Apache Kafka are one of the best high performance and scalable in terms of message queuing. Internet of things platforms usually performs Big Data processing based on Apache Spark or Apache Hadoop [27].

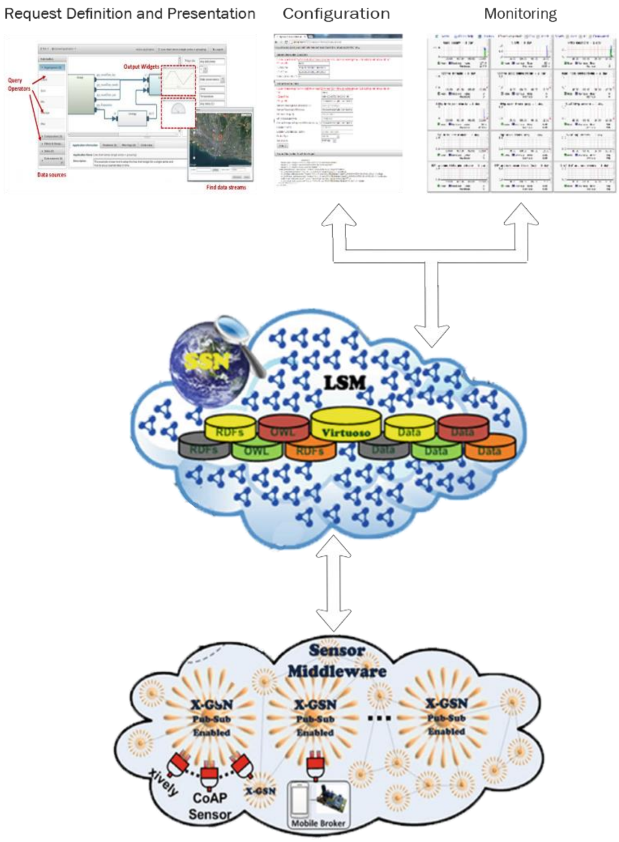


Fig. 6. OpenIoT Architecture [27]

2.4.2 Utility/Application Plane

The Utility plane is composed of three components, namely request definition, request presentation and monitoring. **Request Definition** component provides a Web 2.0 interface so that it allows on-the-fly specification of service requests to the OpenIoT platform. It is composed of a set of services for formulatinf and specifying and formulating web requests, while also submitting them to the Global Scheduler [28].

The second component **Request Presentation** enables the selection of mashups from a specific library in order to provide a service presentation in a Web 2.0 interface. In order to have visualization of these services it communicates directly with the third component known as Service Delivery & Utility Manager, to retrieve the relevant data [28].

The third **Monitoring & Configuration** component provides configuration and the management of functionalities over the deployed sensors and the (OpenIoT) services like sensor integration, that are deployed within the OpenIoT platform. Moreover, it enables the user to monitor the health of the different deployed modules.

2.4.3 Virtualized Plane

Virtualized plane of OpenIoT latform is also comprised of three modules, namely the scheduler, cloud storage and utility manager. The **Scheduler** is responsible to process all the messages requests it is getting from the Request Definition module or web interface to the platform and make sure proper access to the dedicated resources (i.e. data streams) that they require. The virtualize module is also responsible of the following tasks: it manages to discover the deployed sensors and the associated data streams from the sensors that can contribute to service setup; secondly, it enable or select and manages a service the resources involved in provision of services [28].

The virtualized plane also provide **Cloud Data Storage** which is LSM-Light (Linked Stream Middleware Light) provides the storage capability for data streams generated from the sensor-middleware hence serve as the main cloud database of OpenIoT. The LSM middleware is used as cloud storage for the implementation of the OpenIoT platform, which has been re-designed for cloud interfaes with push-pull data functionalities to enable the additional cloud-based streaming processing. The meta data is also stored in the cloud infrastructure which is required for the operations of the OpenIoT platform (otherwise known as functional data) [28].

The **Utility Manager** have dual role in the application plane. Firstly, with help of SPARQL query provided by Scheduler it delivers the Service Request which are indicated by the OpenIoT deliver service request system combines the data streams as deliver the requested service (query provided by the Scheduler) to a 3rd party application or Presentation Request service. To this end, this Internet of Things component is respnsible for the use of the service description reserved by the virtualization plane component Scheduler component. Secondly, it keeps the track record of measuring or metering utility services for each services individually so that metering facility. Resource optimization, billing and accounti related functionalitites drive through this metering component. This is one of the essential feature in the scope of pay-as-you-go scope of utility oaradigm adopted by the OpenIoT platform.

2.4.4 Physical Plane

The **Sensor Middleware** or physical plane is consist of **X-GSN** (Extended Global Sensor Networks) [29] module which is reponsible to filter, collects, combines, and annotates (semantically) data streams from the things or objects i.e. virtual sensors or physical devices integrated to the X-GSN. It enables the connectivity of the things/sensors i.e. physicall world to the OpenIoT platform. The Sensor Middleware is deployed on on the basis of one or more available distributed instances (nodes), which might belongs to the different administrative entities. The prototype or market ready implementation of the OpenIoT platform available at site cirrently uses the GSN sensor middleware that has been extended and called X-GSN (Extended GSN).

2.5 KAA Platform

Kaa is also an open source middleware (cloud based) platform which is developed by the CyberVision Corporation. Which enables various Internet of Things applications, provides development for Internet of Things utility services, and smart products. KAA platform offers a variety of tools for Internet of Things products-development and hence thus drastically reduces risks, development cost and marketing time. The platform also provides device management through cloud connectivity which helps to acquire and provides data analytics, some ready-made prototypes for traditional applications, also support hundreds of thousands of endpoints: can be deployed on cloud or premises. KAA platform offers a sanbox Image to install in VM for small scale uses cases, development, testing or experimentation [30]. It is open-source, hence provides packages and source-code for Kaa cluster installations. KAA is one of the most: easy to learn, deployed and most usable middleware available in the Internet of Things platform market to date. Following section will elaborate on its components followed by architecture to have thorough review before we analyze it performance in the later chapter based on TPC Benchmarking.

2.5.1 Components

KAA platform has three major components. Endpoint SDK enables low layer infrastructure and provides connectivity to the sensors or things enables data management for connected objects by providing server. The SDK is designed to embedd into connected devices and provides two bidirectional exchange of data via the server. SDKs have capability to be integrated into any kinds of objects or devices by providing highly supported hardware agnostic solutions. The high-level component structure is shown in figure 7 below [30].

Whereas the overall functionality of back-end is supported by the Kaa server provides which operates on large scale IoT solutions. KAA server is responsible to handles communication and integration of connected objects, device interoperability, data communication and security and non-failure connectivity. Kaa server also enables to feature established interfaces to integrate the analytics and data management systems. It acts as a scalable-foundation which enables the back-end system that which can be expanding to meet the needs and be able to customize accordingly.

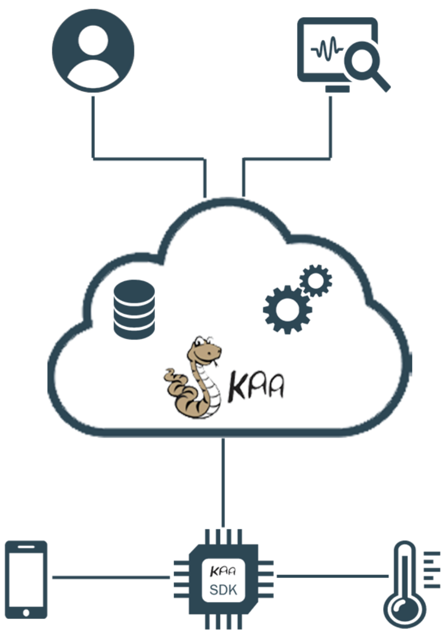


Fig. 7. KAA Platform Architecture [30]

Kaa Internet of Things platform consist of the endpoint SDK and the server component which is integrated into client applications. For more information on the functionality of Kaa server and its architecture, following section will elaborate in detail.

Main features of Kaa are defined as follows [31]:

Event: KAA supports a function which enables messages to be configured for the delivery of event messages between the connected devices. Events could be configured as unicast or multicast based on what it is meant to be sent to single or multiple users. Events are responsible for developing 'event' model for integration of APIs, enforce data validity and security and making sure that the data is delivered to the receiver.

Data collection: Endpoints in KAA platform store data 'logs' for temporary storage in any defined structure. Endpoints SDK then triggers the periodic log upload to the server. Then server comes into picture and upload these logs into the filesystem, which later transferred to the big data analytics platforms, for instance MongoDB or Hadoop for the data analytics. Furthermore, these logs also help to reduce the bugs in the client application, identify and rectify any kind of anomalies, used for user behavior analysis, etc.

Profiling and grouping: KAA proposed the idea of profiling which means that endpoint may consist of server-side parts or client sides parts. Server-side profile is the collection of data sets which is created by KAA Administration User Interface or any REST API configured by the server application. Whereas, Client-side profile is the collection of data sets which are produced by the clients for KAA application. These KAA profiles are managed to sort the endpoint into the groups. These groups then later be utilized for target messages or set notifications for setting up behavior.

Notifications delivery: KAA proposed a system of notifications that enables server to send messages to any endpoints based on a topic-based structure. The access is available only to the groups of the endpoints discussed in profiling sections.

Data distribution: KAA also enables function to data update for configuration, operational data for endpoints etc. This function is used to make the configuration in a centralized manner, for distribution of content, etc. Data schemes may be used by developers or able to define type of data, data structure, and their constraints.

Transport abstraction: KAA also enables vendor freedom by providing the architecture abstraction which enables the centralized configuration for content distribution. It also provides opportunity to choose network stack for communication without any restrictions, for example: Ethernet, CoAP, WiFi, HTTP for building application to connect to any kind of network or end devices.

2.5.2 Architecture

The KAA architecture is easy to understand as it is consisting of three layers and its deployment contains KAA cluster, platform and SDK endpoints. A Kaa deployment is a implementation of the Kaa platform and it consists of a Kaa cluster and endpoints. Multiple server nodes make a KAA cluster. Clients are needed to be registered via endpoints in the KAA platform deployment.

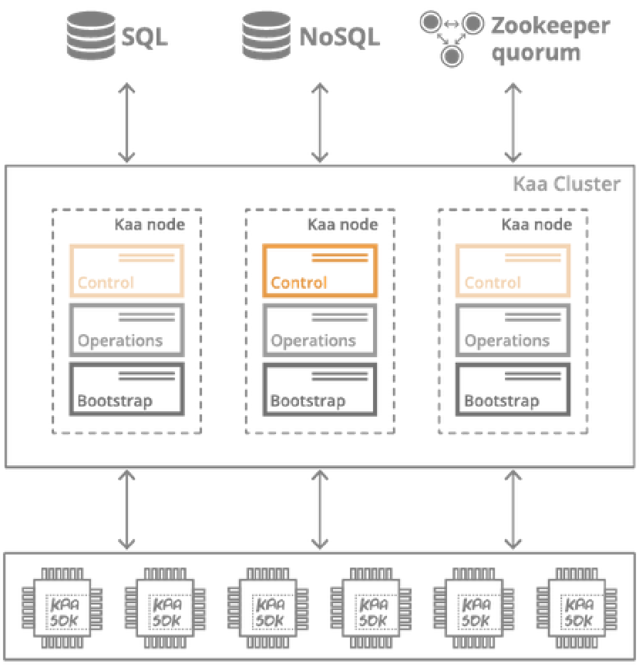


Fig. 8. High Level KAA Architecture [30]

Figure illustrates the high-level architecture of KAA platform where KAA cluster is comprised of various nodes which able to co-ordinate via ZooKeeper for services and NoSQL is used for data storage. It is consisting of Bootstrap, Operations and Control of the KAA services. KAA Control enables the management of data in the system, for example: it delivers data to operations services, it help process the API function call from the webUI to the external system. Moreover, the control service enables webUI which allows developers to create user application, create groups of endpoints, configure and register endpoints.

Operations in KAA is a service which handles the concurrent requests from multiple clients. It is known as worker service. Mostly it is responsible for endpoints processing, register distribution update, and configuration. Horizontal scaling is possible for multiple cluster enablement in KAA platform.

There is also Bootstrap service which is responsible for assigning the endpoint to the Operation Service. Endpoints in KAA platform has built-in bootstrap service for deployment.

ECs are grouped into event class families (ECF) by subject areas. ECFs are registered within the Kaa tenant together with the corresponding event class family schemas. An ECF is uniquely identified to prevent naming collisions during the SDK generation. Once the application and ECF are created, the tenant administrator can create a mapping between these two entities by assigning a certain version of the ECF to the application. This mapping in Kaa is called event family mapping.

2.5.3 Applications

While the Internet of Things has opened up a new technical innovations, which are equally valuable for a broad variety of industries. As figure 2.6 shows[20], Kaa platform provides many good IoT use case solutions on agriculture, automotive, consumer electronics, healthcare, industrail IoT, logistics, smart city, smart energy, smart retail, sport & fitness, wearables, etc

Fig. 9. KAA Applications [30]

2.6 IoT Application Protocols

2.6.1 Constrained Application Protocol (CoAP)

CoAP is an application layer protocol [7], [32] for IoT applications that was designed by RESTful Environments (CoRE) working group and constrained by IETF. This protocol defines a web transfer protocol based on REpresentational State Transfer (REST) on top of HTTP operations. In order to simplify exchanging the date between clients and servers by using HTTP, REST transfer model is used [33]. The REST is described as a cacheable connection protocol which relies on model of stateless client-server schema. It uses HTTP put. post, delete, and get methods, it removes vagueness and it can be used in mobile network applications. This model aslso makes it possible for server & clients to consume and share and the web services, for example SOAP in a simpler method than using Uniform Resource Identifiers (URIs) and HTTP verbs methods and it does not need XML to exchange messages. In contrast to REST, CoAP is limited to use UDP by default, hence it is more appropriate to be used in IoT applications. Moreover, in order to meet the IoT requirements like operating in links contain noise and low power usage, CoAP does some modifiications to set of HTTP functionalities. The exchanging between REST and CoAP protocols in the REST-CoAP proxies is simple despite the fact that CoAP is designed based on REST. The general functionionality of CoAP protocol is shown in the figure below [32].

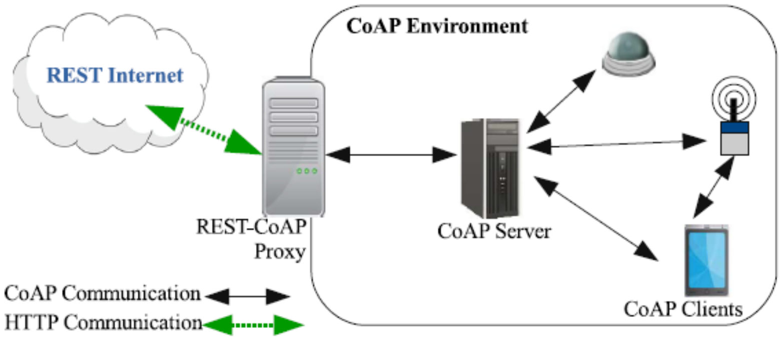


Fig. 10. CoAP Architecture [32]

2.6.2 Message Queue Telemetry Transport (MQTT)

In 1999, Arlen Nipper of Eurotech (formerly known as Arcom) and Andy Stanford-Clark of IBM introduced MQTT as messaging protocol according to IETF and was standardized later in 2013 at OASIS [7]. The aim of MQTT is to connect the networks and embedded devices with middleware and applications. Routing mechanism is used for managing the connection as one-to-one, one-to-many or many-to-many. The mechanism also makes MQTT a suitable protocol for connecting nodes in many of IoT and M2M applications. Many applications in different sectors use MQTT such as monitoring, health care, energy meter, and Facebook notification [32].

MQTT sends messages data through three different levels of QoS, built on TCP protocol. The publish-subscribe pattern is utilized in MQTT in order to provide implementation simplicity and flexibility of transition as shown in Fig. 10. MQTT is also a suitable choice for resource restricted devices which use low bandwidth or unreliable links due to its ability to provide routing for cheap, small, low power memory devices in vulnerable and low bandwidth networks. There are two main specifications for MQTT which are MQTT v3.1 and MQTT-S V1.2 (now MQTT-SN) [27]. MQTT-SN was proposed to be used for sensor networks and adds broker support for indexing topic names and defines a UDP mapping of MQTT. There are three main parts of the specifications: routing, connection semantics, and endpoint.

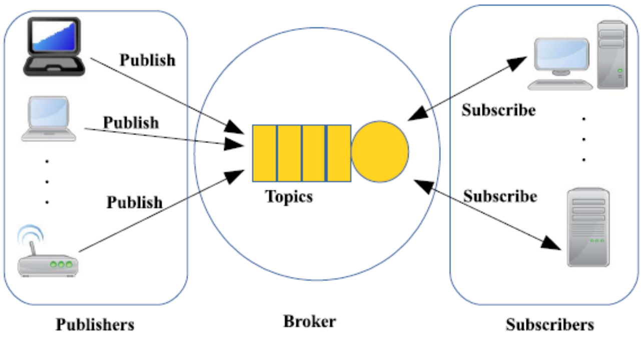


Fig. 11. MQTT Pub-Sub [32]

On the other hand, there are three components that form MQTT, which are the publisher, subscriber, and broker. The operation is done as follows: It starts with registering the interested device as a subscriber for particular topics to be notified by the broker when publishers announce topics of interest. The second task for the publisher is to transmit the information to the previously registered subscribers through the broker. The publisher performs the task of generating data of interest. Moreover, security is accomplished by checking authorization of subscribers and publishers which is the broker's task [33]. The utilization of publish-subscribe process by MQTT is illustrated in Fig. 9 and the message format that MQTT protocol uses is shown in Fig. 11 [32]. The message header reserves the first two bytes of the message. PUBLISH (1), CONNACK (2), SUBSCRIBE (3), CONNECT (8), etc., represent a set of various messages based on their message type field's value.

2.6.3 Advanced Message Queuing Protocol (AMQP)

The IETF's standardized application AMQP [7] is an open layer protocol for the IoT which mainly focuses on the message-oriented environments. AMQP supports the publish-subscribe communications approach. Reliable communications are supported by AMQP via its three types of primitives for ensuring message. This protocol requires using TCP as a reliable transport protocol to send and receive messages and it defines a layer of messaging the effect on top of its transportation layer where it enables the messaging handled. AMQP implementations can interoperate with each other, by defining a wire-level protocol. There are two main components to handle the communications: the message exchanges and queue. The exchanges are utilized for routing the messages to suitable queues based on pre-defined orders and conditions. It is possible to store the messages in message queues and then forward them to receivers. There are two types of messages defined by AMQP: the massages supplied by the sender (bare messages) and annotated messages could be seen at the receiver side. The format of AMQP’s message is illustrated in [32]. Conveying the delivery parameters such as priority, durability, first acquirer, time to live, and delivery count, is the responsibility of the header.

3 BENCHMARKING METHODOLOGY

3.1 Cloud-Based Architecture of IoT Platforms

Generally, in [7], [22] and [26] there are fundamental elements proposed of the IoT platform based on PaaS definition:

1. Physical Layer: sensors, actuators, embedded communication hardware and Connectivity.
2. Middleware: storage and computing resources for data handling and prediction.
3. Application: User Application, Utility Management, data visualization and M2M communication.

3.2 key Parameters Indicators

3.2.1 The Ingestion rate or arrival request per second

The ingestion rate or otherwise known as arrival request is defined as the data ingestion by the sensing layer or messages by sensors, it is usually expressed in requests per unit of time (e.g., per second). The gateway or the middleware of the platoform or system is required to process and ingest load from the sensing layer. The stress test usually is determines the load handling capacity of the system my increasing the load or data into the system and test the limit. Rapid increase in the arrival message requests requires the system to acquire that data (buffer) then process it means need of computational resources and results in queue which ultimately raised the response time or iverliad the system. That point is klnown as system crash state [34-35].

3.2.2 Data Distribution (buffer distribution)

The ingestion rate only defines the average arrival rate of the load of data per unit time, but it doesn’t clarify the over-all distribution of data over long period of time. The amount of ingestion data, for example, be distributed evenly spaced or linearly distributed or could occur about the similar time fashion with specific offset of time period. Mathematically, distributions, for example: Bell disribution, Gamma, or Poisson or normal distributions are

are often described as statistical distributions which states the oevr-all pattern or curve of the laod over time interval to specify the anture of load [34-35].

3.2.3 Messaging Protocol (size, time, processing)

Messaging protocols also plays a vital role in terms of performance as they vary in overheads, technology and how the size of information is managed. Transport protocols for IoT like MQTT, CoAP or NGSI have varying overheads bytes when it comes to memory allocation, messages processing time, or bandwidth distribution. Potocols for Internet if Things needs to be reengineered or push to reduce the overheads so that it will be efficient for load management [33].

3.2.4 Network Bandwidth (protocols overheads, processing and memory)

Network Bandwidth is totlally depends upon overhead processing, message transmission period and disk I/O which overall has combined affect on transmission unit or Bandwidth of the sysytem [34].

3.2.5 Instance Type (i.e. based on platform what instance is assigned)

In cloud computing the instanes are defined as the unit of resources allocated for the specific virtual machine hence they have varying performance features. For example, Amazon Web Services define instances as size of RAM, the assigend CPUs virtually, and also network capacity which is usually defined as high, moderate or low. Amazon Web Servcies also provide instances for specific pupose, for example: memory based, compute optimized, or Input/Output based optimization of instances. These parameters directly affect the performance of the application as if instances are based on computational resources assigned to them [35].

3.2.6 Smart City Scenario

The smart city concept is a form of interconnected physical world and utility services by the Internet of Things systems which creates the opportunity for smart city market. In today’s market the bottlenecks are customized building block of IoT systems, lack of standardization, incompatible architecture no or less interoperability between the services, that creates an opportunity for forums like EU to play stockholder and start initiatives like INTER-IoT or bIoTope. Table I illustrate some of the features and requirement in this regard [10] and [36].

Dameri introduce the definition of smart cities as:

”*A smart city is a well defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well being, inclusion and participation, environmental quality, intelligent development; it is governed by a well defined pool of subjects, able to state the rule and policy for the city government and development*” [10].

TABLE I Smart City Service Requirement [10,36]

Smart City Requirement	**Cloud Architecture Component**
Ability to interchange information amongst the Internet of Things systems and within the IoT system	Edge networks, Cloud, Internet of Things Gateway
Standardization in communication protocols for IoT	Device management, Internet of Things Gateway, IoT Connectivity and transformations
System access or remote control	API management, Devcie handling and Edge Services
Ability to acquire data from different resources and make decisions for utility serviecs	Visualization of data, data analytics
Data integration from different resources	Edge Services and Internet of Things Gateway
On time data services	Data analytics and Edge Servcies

3.3 TPC-IoT Benchmarking

Founded in 1988 [37], the Transaction Processing Performance Council (TPC) is an independent body that targets, create and maintain benchmarks to measure performance in standardized, objective and verifiable manner. Last year, they publish TPCx-IoT Benchmark as IoT is being adopted across almost every industry triggering a massive influx of data that must be analyzed for insights. Typical IoT topology consists of three tiers: edge devices, gateway systems and backend data center.

TPC-IoT provides a promising measure of hardware, data storage, operating system and data management systems to provide the IoT industry with verifiable performance, availability metric, price-performance for systems which are meant to ingest and persist massive amounts of data from large number of IoT devices, and provide real time insights, typical in IoT gateway systems running commercially available software and hardware [38].

Following figure shows the high-level architecture of the benchmark as it sits between the sensing layer and middleware as IoT gateway.

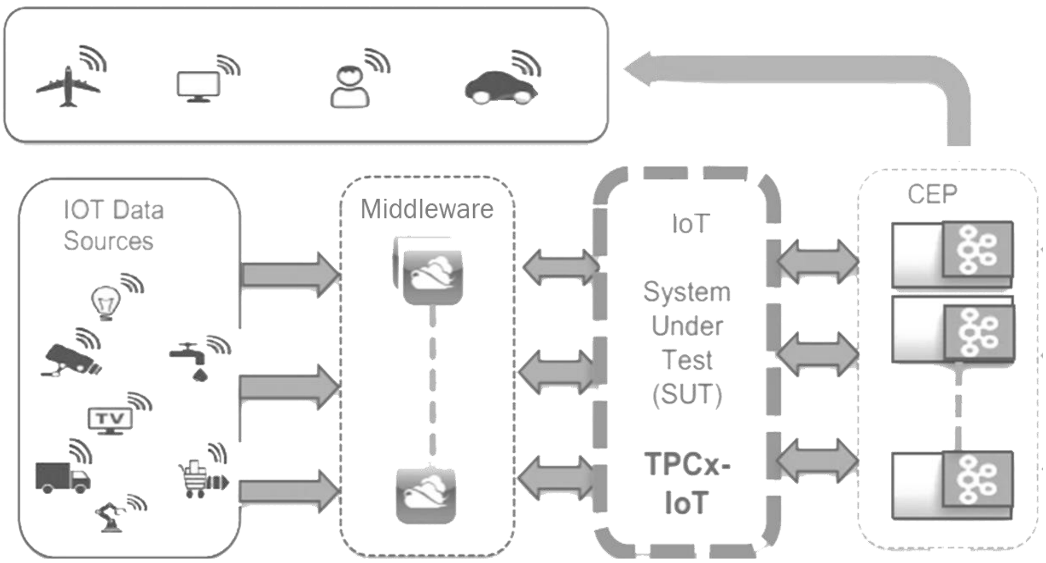


Fig. 13. TPC IoT Benchmark Architecture [37]

The Internet of Things gateways are responsible for several purposes:

• Standardization of protocols for the connecting diffrent devices.

• Internet of Things gateways will be enable to filter, store, and verify data so that the end devices or sensors will be less stressed as they have limited capabilitites.

• It will help to build data analytics easier and make decision making more instatnt by providing data from otehr oarts of the system.

• Current interne tof things gateways will be enable to compute and function as computing platform or near to their performance. This feature will help to put logics and analytics near to data acquisition system hence it will result in abetetr times response fo rsome critical applications.

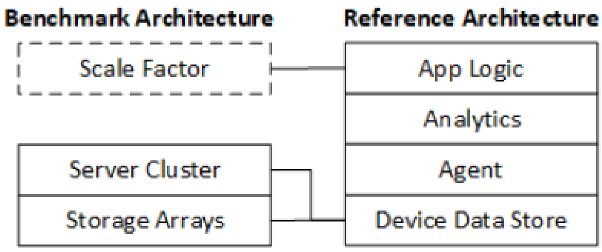


Fig. 14. Reference Architecture for Benchmark [38]

3.3.1 Performance Metrics

Scale Factor: The current version of the TPCx-IoT Kit follows a continuous Scale Factor. Scale Factor is defined as the number of records to be ingested. Benchmark sponsor can pick any Scale Factor [37].

Metric

TPCx-IoT defines the following primary metrics:

1. IoTps, the Performance Metric
2. $/IoTps , the Price-Performance metric
3. System availability

Performance Metric

The performance metric is used to define the effective or overall throughput of the System Under Test IoTps = SF/(T) Where SF is the Scale Factor. See Clause SF T is the time elapsed in seconds.

Price Performance Metric

The price-performance metric is defined as: $/IoTps = P/ IoTps P represents the total cost of the system under test.

3.3.2 Qualify for Evaluation?

The following characteristics shall be used to make this judgment:

• Is it complicated to setup the environment? What about the documentation and customer supprot?

Yes (for both platforms).

• Does Is there any limitatioons by the servcie provider about implementations which restricts the TPCx-IoT benchmarking of the platform?

No (for both platforms).

• Is What about the archotectural implementation of the platform which might affect the some parts or tools for the application devvelopment for any specific utility?

No (for both platforms).

• Is the available platform set-up is not supported by vendor for any specific region or any other restrictions? (This might includes promotion of similarity to other products and technologies.)

No (for both platforms).

• Does the setup needs some extra non standardized sophistication on the side of the system admin, programmer or enduser?

No (for both platforms).

• Are there any implications in the released versions, for example purchasing license or some specific application in the market which can not benefit from it? How penetrating is the market? How many end-users can be benefited from it?

Yes (for both platforms).

• Is it opensource or based on pricing, if later case is valid then how the TPC pricing maetriz fit the case, based on the rovided documentation.

Opensource (for both platforms).

3.4 Proposed Benchmarking Methodology

Based on literature review and keeping other factors into account the proposed benchmarking methodology is composed of four major domains as shown in figure 4. Each domain is further explored into factor which are described in detail.

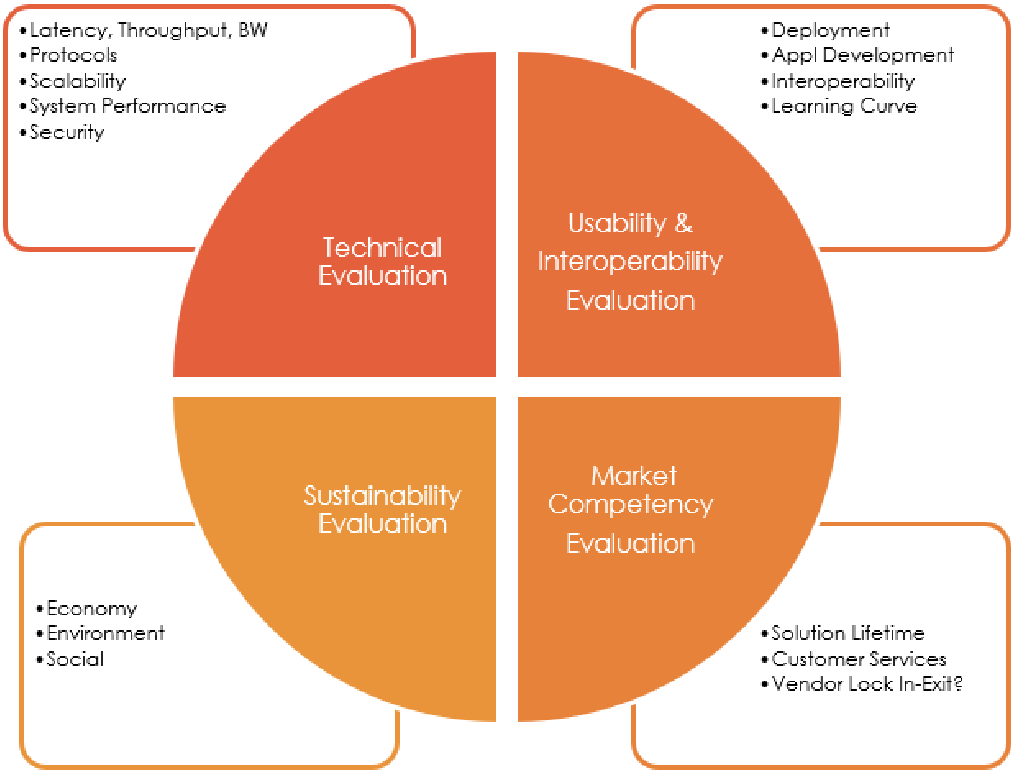


Fig. 15. Proposed Benchmarking Methodology

3.4.1 Technical Evaluation

Network, network parameters for QoS, for instance latency, bandwidth, jitter, capacity packet loss etc can leave devastating effects on overall performance. It depends on how the overall network architecture is implemented let say for propagation of data from an endpoint (sensor and/or device) to be processed by rule engine in the cloud back-end and then the response is sent back to the application [40].

In the network layer, traffic of the networks is usually determined in one of the two ways: 1) B class services which can sustain delay, they are data base based services which rely on heavy analytics but not time sensitive. 2) Time or delay sensitive services, includes application or services which require instantanous analytics [41]. Following is one of the solutions for such services 1) capacity of the network shoudl be maximize by increasing the BW so that throughput will increased without compromising the Qulaity of Service [40]. 2) Consider the jitter, throughput and delay into account while allocation rate. 3) Throughput needs to be optimized and power or energy efficiency strategy should be designed for network layer.

Protocols, most common application layer protocols used in IoT are MQTT, CoAP, AMQP, XMPP being supported by IoT platforms while MQTT and CoAP are widely used [33]. MQTT is a lightweight protocol and has much lower overhead due to its pub-sub binary nature. However, as system will evolves in future, protocols need to be evaluated to accommodate more devices or reduce messaging latency which can affect the overall performance of an IoT system or platform.

To make our case, below we are comparing the two most commonly used IoT application protocols [41] as use-case and their effects on performance in table II [42].

TABLE II Comparison of MQTT and CoAP [42]

Parameter	**MQTT**	**CoAP**
Latency	High	Low
Packet Loss	Low	High
BW Consumption vs Packet Loss	Very Low	High
QoS	✓	✓
RESTful	✗	✓
Transport	TCP	UDP
Request/Response	✗	✓
Header Size (B)	4	2
Security	SSL	DTSL

Scalability is the ability of the system to accommodate the increasing load or elements gracefully without degradation of performance into the process. It is one of the most crucial element of the IoT infrastructure which effects the performance and the biggest USP of every cloud platform provider in the market. There are different types of scalability, load scalability is one of the element of cloud-based IoT platform is subjected here which effect largely on performance (directly effects on resources, throughput and jitter of the platform) [43].

Designing an IoT infrastructure for handling 100 devices is totally different from one which can handle a million or scalable. Increasing number of sensors cause increase in load which require the processing of more data and analytics to generate responses. A usual approach to address this issue is to creating load balancers and distribute load over multiple servers via clustering which leads to increase in latency between the nodes [44].

System Performance: Every IoT platform initiate rule-based triggers, which are automatically raised once an event happens or anomalous data enters into the system. As more and more devices will get connected to the cloud back-end platform, the average time it takes to handle and analyze each event will increase eventually. A simple performance criterion for any IoT device is to trigger a signal and measure the average time or latency it takes for the cloud platform to take an action on that event [45].

Edge Computing with the pace IoT is growing, the future of platform is shifting towards distributed, edge intelligence. As edge devices or gateways are becoming more powerful, it is possible to take autonomous decision using local data rather than putting load of each instance to cloud unless there any anomaly is found. It can increase the application performance due to less delay and less load on back-end cloud [43]. Here it needs to be emphasized that there are significant differences in scale between cloud and edge computing as cloud has non-comparable communication, storage, compute and data analytics capabilities in comparison to edge [45].

Fig. 16. Shows the architecture of cloud back-end and edge-gateways to deliver services to the end-user.

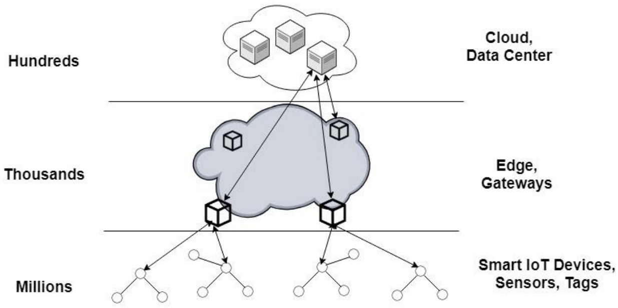


Fig. 16. Edge Gateways within Cloud [45]

It can improve IoT platform for the optimal performance based on following features which make huge impact on performance:

- Location
- Distribution (storage, compute and communication)
- Scalability (Network, load, and virtualization)
- Density of Devices
- Mobility Support
- Real-Time Response

Backup/redundancy: Outage can happen in any IT system so is the case with IoT Platform. There are some questions to be addressed while assessing any IoT platform. For example, does this cloud-backend provide data backup plan? How often it takes place? What if any cluster goes off? Is there failover provisioned? Is it shared or dedicated services within customers?

Security: It is one of the significant challenge in IoT due to the lack of standards and architecture as it is still growing. As the scope of IoT infrastructure includes many heterogenous devices, system and networks, it is a very challenging task to provide security and privacy to the users or endpoints. As there are hundreds of endpoints.

3.4.2 Usability & Interoperability

Interoperability: As of the vision of IoT for being connected to anything, anytime, and anywhere will rise the heterogeneity among the IoT systems and platform making it hard to be interoperable the devices, software or services amongst other IoT platform [47]. Just imagine the situation of smart city where hundreds of IoT platform are deployed and they are not interoperable it will be huge over utilization of resources. To target the issue of Interoperable IoT systems, the INTER-IoT aim to design and test IoT framework which will allow voluntary the solution of interoperability amongst the different IoT platform using a bottom-up-approach [48] under the EU funded project for H2020. INTER-IoT will encourage any stakeholder to to design devices, services, platform based on existing eco-system and solution more interoperable in the market or smart city scenario.

Deployment of Platform: how easy to deploy platform and it services. If it is user friendly or no. Such factors are also important for the ease of end users.

- Application Development
- Learning Curve

3.4.3 Sustainability Aspects

The objective of Sustainability is to encourage the prioritization of sustainability goals by UN as part of the design of commercial projects in IT industry to maximize social impact, environment and economic effect while delivering, and potentially increasing, commercial value. TPC is currently working on its new benchmark on energy efficiency in IoT platform which can be crucial guide for assessing one of the pillar of the sustainability. These three main pillars of sustainability which needs to account while designing, implementing, commercializing any IoT platform

- Economic
- Environment
- Social

Sustainability is a concept which is defined earlier in the first chapter that it creates balance the way we utilize the resources so that we can use servcies or resources to fulfil the current needs without leaving the negative impact on the environment so that the upcoming generations will have their share. In software systems or IT technologies it is defiend as the capacity of software system to endure in certain ecosystem under current and future conditions while satisfying the needs of users today and tomorrow without impacting negatively on the environment and continuously support business growth and societal values [49].

Sustainable software design is one inwhoch the services or the application of the software, direct or the indirect will have least negative impact on the environment while have best practices for human, help to raise the business or economy, easy to deployed, less resourceful, easy to modular for future upgradation, follwoing the standards or least customized. Such design or solutions are easy to reuse, scalable, portable or eas yto maintain and efficient.

Individual sustainability is usually target the efforts by the individual human to maintaine the software system or engineering(SE), for example: How can a software or IT soulution may be designed which can help developer to create and maintaine it so that it can satisfy its job over a long period of time. Whereas social sustainability defined as preserving the social communities and maintaining the capital. For SE: What effects do software systems and applications have on the society (e.g. communication, interaction, government)? Economic sustainability aims at maintaining assets. For SE: How can software systems be created so that the stakeholders' long term investments are as safe as possible from economic risks? Environmental sustainability seeks to improve human welfare by protecting natural resources. For SE: It is one of the important question to rasie that how the software development affect the enviroment after or during the development phase? Furthermore, technical sustainability raise awareness regarding how long the solution will be persistant? And adequate for the upcoming situation? SE: How it will be able to adopt the changes or how modular it is in nature?

3.4.4 Market Competency

Just imagine an industrial manufacturer consuming IoT services using an IoT platform, and with the pace of technological advancements it is likely to raise question about the life time of the solution as older systems are becoming discrete new versions of sw are available so one need long-time support. It is very important to achieve a vendor/technology solution which is easily transferable or upgradable in case such need arises. Avoiding vendor lock-in is one of prime importance while creating a future-proof architecture for IoT platform

[52]. One should keep in mind while availing the services:

- Solution Lifetime
- Community/Customer Service
- Vendor Lock In/Exit

4 EXPERIMENTS AND RESUTLS

We have discussed the both platforms, OpenIoT and KAA in detail in literature review chapter and later proposed a benchmarking criterion for Performance Evaluation in 4 step process which includes; technical evaluation, Usability & Interoperability, Market Competency and Sustainability. This chapter we will discuss how we design experiments for technical evaluation (due to time limitation only one of the evaluation process is being tested) based on TPCx-IoT benchmarking criterion i.e. message delivery from the end points and secondly data ingestion capability i.e. data collection from many endpoints or sensors.

4.1 Experiment Environment

To evaluate performance two scenarios are designed based on TPCx-IoT criterion. Both are very simple and applicable to any type of IoT platforming the market. First scenario examines the delivery between two end points in IoT system. It’s very common in IoT platform that IoT application has to send messages between the nodes or end points for any kind of use case be it environment monitoring or smart transport system. Second scenario is based on data ingestion principle, collecting data for post processing or analytics. It’s like a scenario where one node is collecting data from multiple end points for instance KAA SDK or X-GSN module in respective platforms. The experiment environment considers locally in one network i.s. LAN as we are not measuring cloud performance. Figure 16 shows the overall atrchitecture and details of experiments will be discussed in section 4.1. In both scenarios the end points deliver messages through IoT platforms. The details are mentioned in section 4.2 and 4.3.

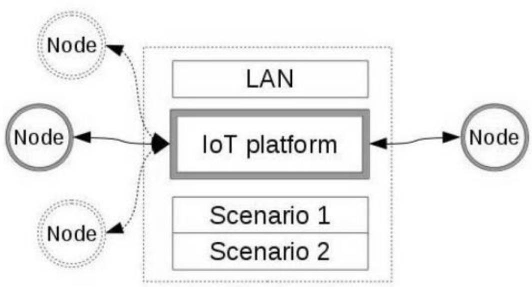


Fig. 17. Overview of Implementation

Experiment environment where we discussed two scenarios are explained here. KAA platform has a central server where all the end points get connected. To limit the overall network behavior and other complications we put all the nodes in the same network i.e. LAN (Local Area Network). The overall experiment topology is shown in the figure 17. It is necessary to mention here that KAA sandbox is implemented as a single server in Virtual Machine instead of a cluster. Private IPs are used for all the devices in the LAN,

1 Raspberry pi with Linux occupying 512MB memory.
2 Laptop with Linux 4GB memory.
3 VirtualBox VM for KAA sandbox running on 4GB memory.
4 Nodes are implemented in laptop and pi.

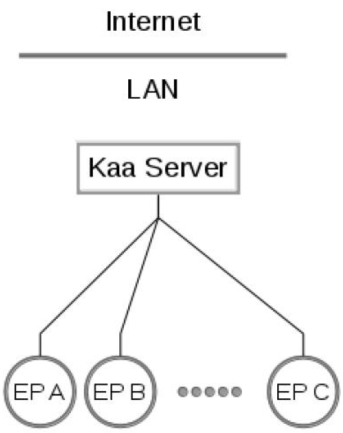


Fig. 18. Experimental Topology

4.2 First Scenario

The main function as described earlier in the first scenario is message delivery among the two nodes or end points which is considered as the fundamental operation in any Internet of Things application. Different increasing ranges of data rates will be used to test system under test for measuring its capability of handling messages.

As illustrated in figure 18, there is exchange of messages among the 2 nodes. Where node A sends packets or messages continuously to node B and B sends a response back as acknowledgment if the message is received successfully. At the node A we can measure time taken by messages by time stamping, later with series of arrival time we can analyze the performance of message handling by increasing the rate of messages between the two nodes.

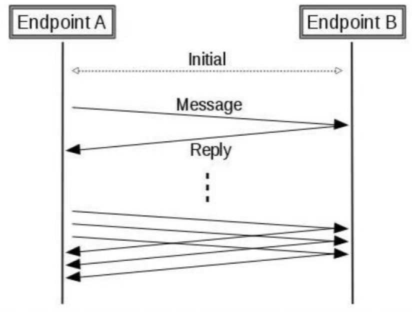
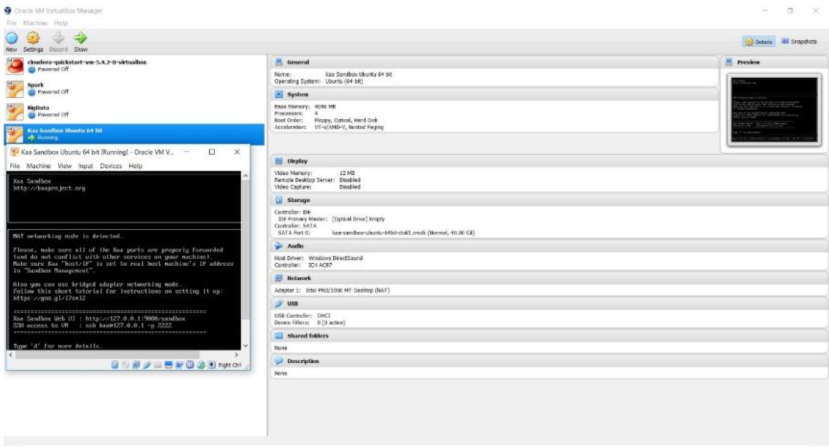


Fig. 19. Messaging Work Flow

KAA platform has an Event subsystem to balance the load of the messages between the nodes. It's a module provided by the kAA platform. Event classes needed to be configured as well as define event family to address the message structure. Every event contains a time stamp of data type long. Using Web User Interface of KAA we generated SDK. Configurations settings of Event Class and Event Class Family are provided in Appendix A. KAA sandbox run as central server where A and B nodes sends message through it.

End point A which is laptop and End point B which is raspberry pi, first estyablosh a connection to the central SDK server. Then A starts sending packets or messages to B periodically. All the messages known as events are first handled by the SDK server then it send to B. If B received the message it send back acknowledgment to the A via the same route. As soon as A gets the response it calculates the time period using the above mentioned technique. Each of the rounds contains hundreds of messages and delivery time may vary from 10ms to 1kms. Following small snipet is provided for this simple scenario. The detailed code is provided in appendix A.



Data Schema	Configuration Schema

{
"type": "record",
"name": "DataCollection",
"namespace":
"org.kaaproject.kaa.schema.sample",
"fields": [
{
"name": "temperature",
"type": "int"
}
]
}
	{
	"type": "record",
	"name": "Configuration",
	"namespace":
	"org.kaaproject.kaa.schema.sample",
	"fields": [
	{
	"name": "samplePeriod",
	"type": "int",
	"by_default": 1
	}
	]
	}

Fig. 20. Example Snippet

4.3 Second Scenario

In the second scenario, which is also one of the common feature in any application in IoT applications. It is to data ingestion, or otherwise getting data or messages from all the sensors or end point and collect them in a single node to store and forward to the cloud for data analytics. So in this scenario we implemented multiple endpoints to deliver multiple messages to the sever to evaluate the platform performance. Figure 19 illustrates the the handling of messages in this scenario. Although kAA platform has a powerful sever to handle this messages load.

It uses it log subsystem to to periodically handle data to the server. The log system enables end points to push load to the server. Where as it receivers messages to store them in adatabase, sends back an acknowledgment to the endpoints. It is similar to log schema and needs to be pre-configured. For the fair load distribution and measurements all the source modes are configured on laptop.

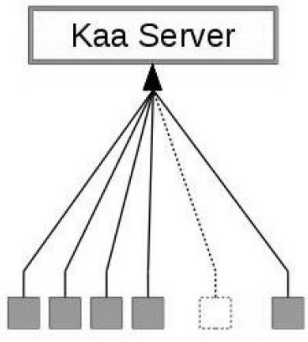
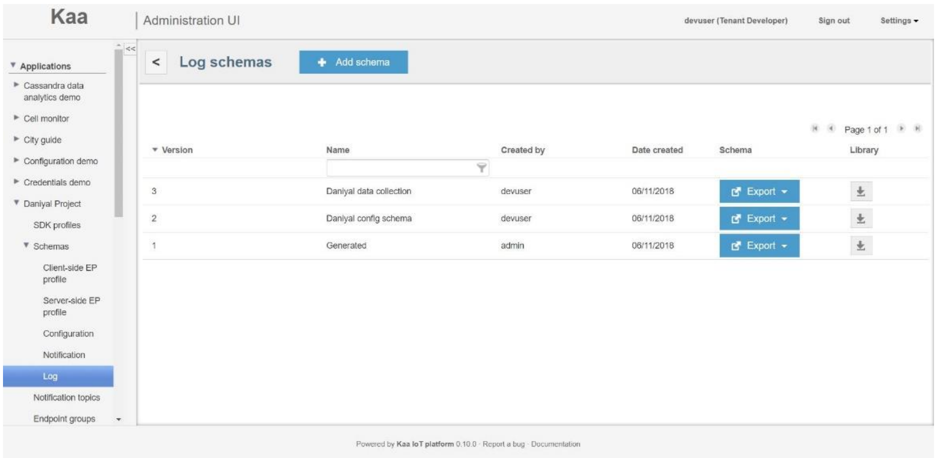


Fig. 21. Multiple Endpoints Scenario

KAA platform uses its subsystem to send periodically messages via log system to the sdk server. It’s the functionality of the log subsystem to allow all the custom messages to be sent to the server. After receiving the messages the KAA server stores them in a database and later send the acknowledgment to the end points. It is similar as the Event subsystem, the long format of the long massages is needed to be customizedto be preconfigured in log schema. You can find the log schema in appendix A.



Log Schema
{ "type" : "record", "name" : "IoT_Test_For_S2", "namespace" : "com.company.project", "fields" : [{ "name" : "NodeID", "type" : { "type" : "string", "avro.java.string" : "String" } }, { "name" : "MsgID", "type" : "int" }, { "name" : "timestamp", "type" : "long" }] }

Fig. 22. Log Schema Snippet

4.4 Results

Finally, we will discuss the results obtained from the above two scenarios. We use excel for processing data to analyze different graphs and later explain those curve in each scenario.

4.4.1 First Scenario

For first scenario we set delivery time interval as 10, 50, 100, 500 and 1000ms. For each interval, the messages exchanges between the endpoints is 100. Below table shows standard and avg. deviation of time stamps. It can be observed that during shorter intervals, for instance 50 ms the average message exchange time stamps is in 1000s while for longer intervals it is around 100ms.

The standard and average deviation of time interval for message exchange of KAA platform is shown in the table 3 It can be observed clearly that for intervals shorter than 50ms, the exchange time interval of exchange messages is in 1000s. And for intervals longer than 100ms, the exchange time interval of exchange messages is in 100s.

Table III Message Delivery Intervals of KAA Platform

Intervals (ms)	10	50		100	500	1000
Average Time (ms)	4638.41	2398.83		126.73	109.31	163.59
St. Deviation	907.88	1484.72		87.13	59.16	129.9

Fig. 23 clearly illustrates that for smaller delivery intervals, for instance 50 ms or less; the average message exchange time increases smoothly upto 5000ms with the incerement of packets or messages and then goes stable after about 40 packets to the level of 5500ms. Whereas for the delivery intervals higher or equal to 100ms the average message delivery time remains stable around 200ms.

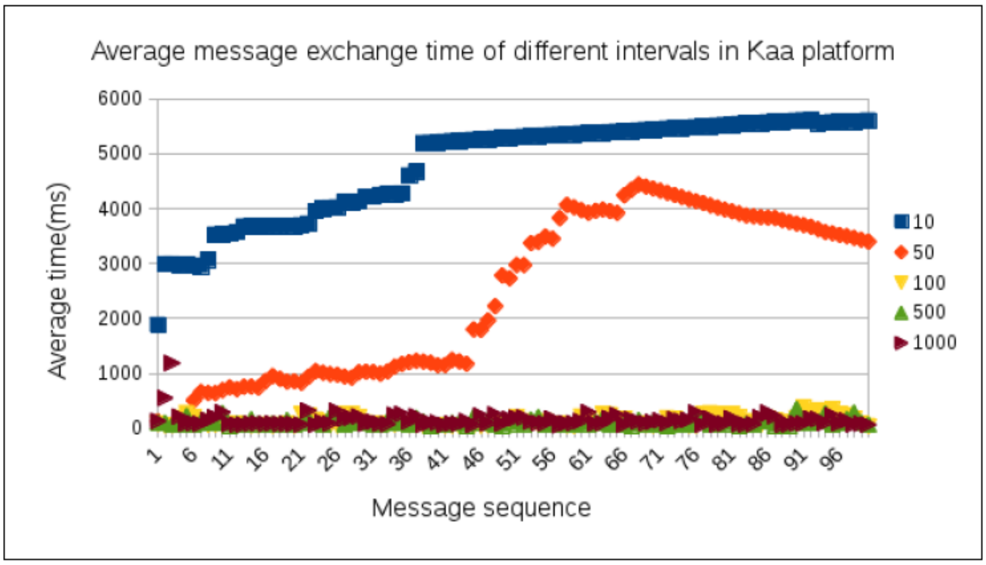


Fig. 23. Avg. Time for Delivery Time Intervals

4.4.2 Second Scenario

Some of the prominent values of the results from the second scenario is shown in table 4. The endpoints vary from 4 to 2o in this case. As it can be observed that the average round-trip time rises with the increment of number of end points, but some anomalies can also be seen for the values of 16 and 18. Delivery time out cases can also be taken into accounts whenever the roundtrip time is more than 6o seconds (end points acknowledge the KAA server for such cases). For the standard deviation, it has the trend of direct relationship with the increment of number of endpoints.

TABLE IV Data Ingestion and Standard Deviaton [53]

No. Of Endpoints	4	6	8	10	13	14	16	18	20
Avg. RTT (ms)	57.17	151.91	163.76	223.39	287.51	511.87	305.71	426.87	912.01
Std. Deviation	191.3	526.65	487.28	607.25	645.98	1043.7	759.37	793.8	2179.7

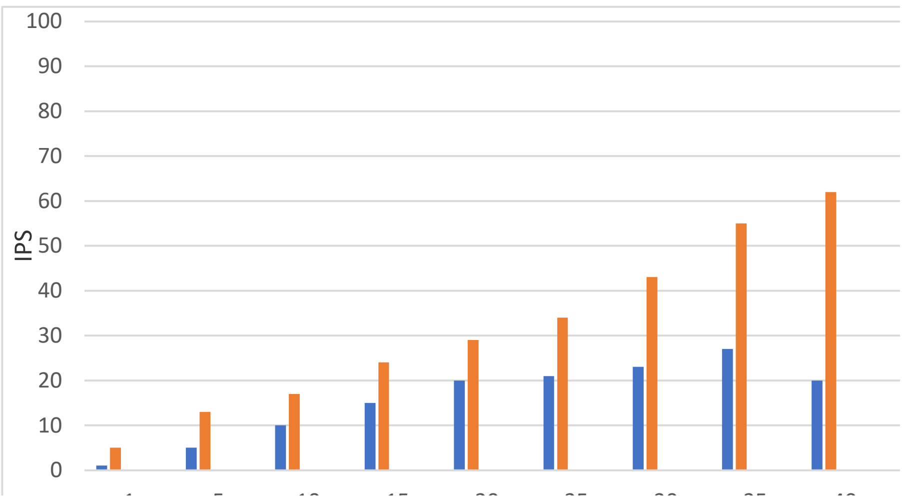


Fig. 24. Ingestion Rate of KAA vs OpenIoT

5 CONCLUSIONS AND FUTURE WORK

In this thesis, we proposed a methodology comprised of four different evaluation, for instance Technical Evaluation, Usability/Interoperability Sustainability and Market Competence including Technical Evaluation based on TPC-IoT benchmarking to evaluate the performance of any IoT platform. This research is to provide insight into key parameters in each layer of the platform affecting the overall performance. Air quality monitoring using an open-source IoT Platform as a use-case is used for the deployment of methodology (technical evaluation). A preliminary evaluation of data ingestion of open-source IoT platform is evaluated presented based on benchmarking methodology (TPC-IoT) as a use-case how to evaluate performance.

In future, comparison of different IoT platform can be evaluated to provide an insight how this research can be a guide for evaluating and choosing the right platform for specific application. Furthermore, some key parameters needed to be study in detail as mention TPC benchmarking is coming soon on Energy Efficiency of IoT platform as it is one of the main parameters of sustainability point of view.

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APPENDIX 1.

Scrrenshot of platform.

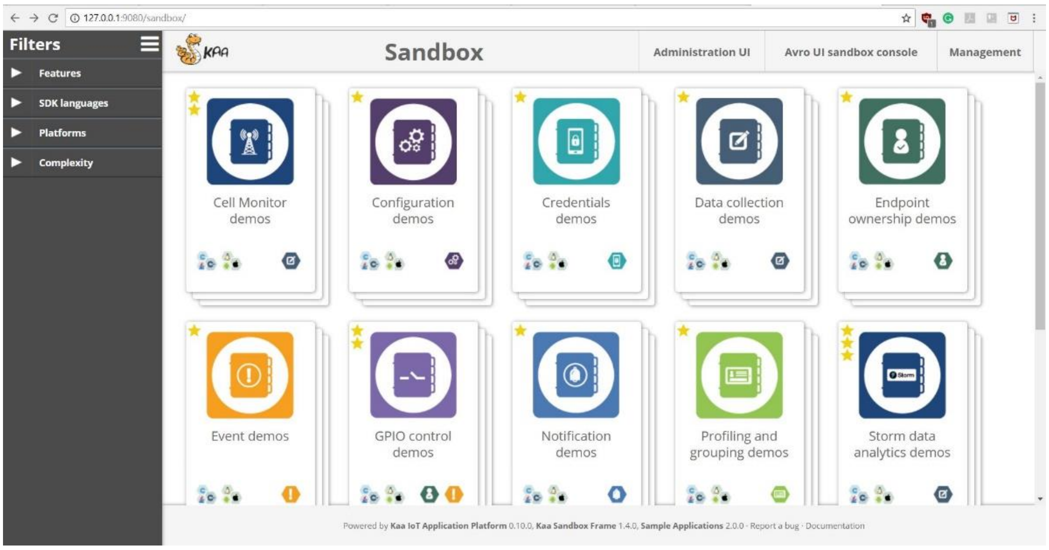

Table of values of Ingestion [53]

No. of Sensors	Openlot IPS [1]	KAA IPS
1	5	5
5	10	13
10	15	17
15	20	24
20	21	29
25	23	34
30	27	43
35	20	55
40	20	62
45	20	78
50	20	92

APPENDIX 2.

Codes for the implementation of scenarios I and II.

https://github.com/DaniyalAkhtar?tab=repositories