Highlighting the Key Factors of an IoT Platform

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***Abstract* - The Internet of Things (IoT) is a hot topic in the engineering and technology community, and IoT-enabled devices are becoming increasingly common due to advancements in technology. IoT platforms provide valuable and specific services for IoT applications, and the number of platforms used by IoT applications is growing rapidly commensurate with the increasing number of IoT devices. However, fierce competition between IoT platforms is making it difficult for companies to select a suitable type of IoT platform for their business needs. This paper attempts to identify the important factors of IoT platforms that can be consider before selecting an IoT platform. In this paper, Twenty-one important IoT platform factors are identified from the literature and these factors were then verified by the Delphi method and categorized. This paper aims to help companies choose an appropriate IoT platform from the huge number and variety of IoT platforms available in the market.**

Keywords - IoT, IoT platforms, IoT components, key-factors, Protocols

I. INTRODUCTION

The term "Internet of Things", abbreviated "IoT", was introduced by British technology entrepreneur Kevin Ashton in 1999 as the title of a presentation at Procter & Gamble (P&G) and can be defined as small and complex systems that allow businesses, governments and citizens to adopt and interconnect physical objects and virtual objects based on existing and evolving interoperable information and communication technologies [1]–[4]. An IoT platform enables IoT device and endpoint management, connectivity and network management, processing and analysis, data management, application development, access control, security, monitoring, event processing and interfacing [5]. Recent growth in mobile devices, embedded technologies, cloud computing and data analytics has resulted in a boom in IoT utilization, for both personal and organizational use, to conduct information exchange in order to facilitate recognition, monitoring, tracing, positioning and administration [5],[6]. For example, Williams [8] stated that in 2015 the number of IoT platforms was almost 260, which grew to 360 platforms in 2016, and exceeded 450 platforms in 2017. Requirements for IoT platforms, which provide important services and features for IoT applications, change as new IoT devices emerge [9]. Lee [10] identified 4 types of IoT platforms namely end-to-end, connectivity management, cloud and data. This complexity in the context of rapid change poses challenges for businesses, governments and citizens, who often have little experience of the infrastructure of IoT and little knowledge of how to select an IoT platform that can meet their current and future needs.

This paper aims to help companies or organizations address key factors in IoT platform selection and thus enable them to find and choose a suitable IoT platform for their business.

The rest of the paper is organized as follows. Section II discusses building blocks of IoT and important factors of an IoT platform, section III discusses research methods and data collection, section IV presents Delphi study results, and section V discusses the findings and concludes the paper.

II. RELATED RESEARCH

IoT application needs a platform to run smoothly and provide the data so that the companies take some future decisions based on the data received from the IoT platform [11]. Hundreds of IoT platforms are available and finding the most suitable IoT platform for a specific IoT application is becoming increasingly difficult. The problem is compounded by a lack of experience and knowledge, and in some cases, a company may select a platform without adequate requirements analysis, which later leads to problems [9].

The question thus arises: "what important factors should be considered before selecting an IoT platform?"

The literature review structure is similar to [13] and the literature review had two main objectives:

- To identify the building blocks of IoT.
- To identify key factors of IoT platforms.

A. IoT Building Blocks

In order to understand the functionality and significance of IoT, it is essential to understand its building blocks. Building blocks are the components of IoT, that work together to deliver the functionality of IoT. There are six IoT building blocks that work together and provide functionality [12], as shown in Fig 1.

Identification block: The identification method is used to identify devices in the network. Devices are identified with the Object ID, which is the name of the device, and the object address, which provides the address of the device in the communication network [14]. The main addressing methods of IoT objects are IPv6 and IPv4 [12].

Sensing block: Sensors are used for collecting the data of objects in the communication network and sending the

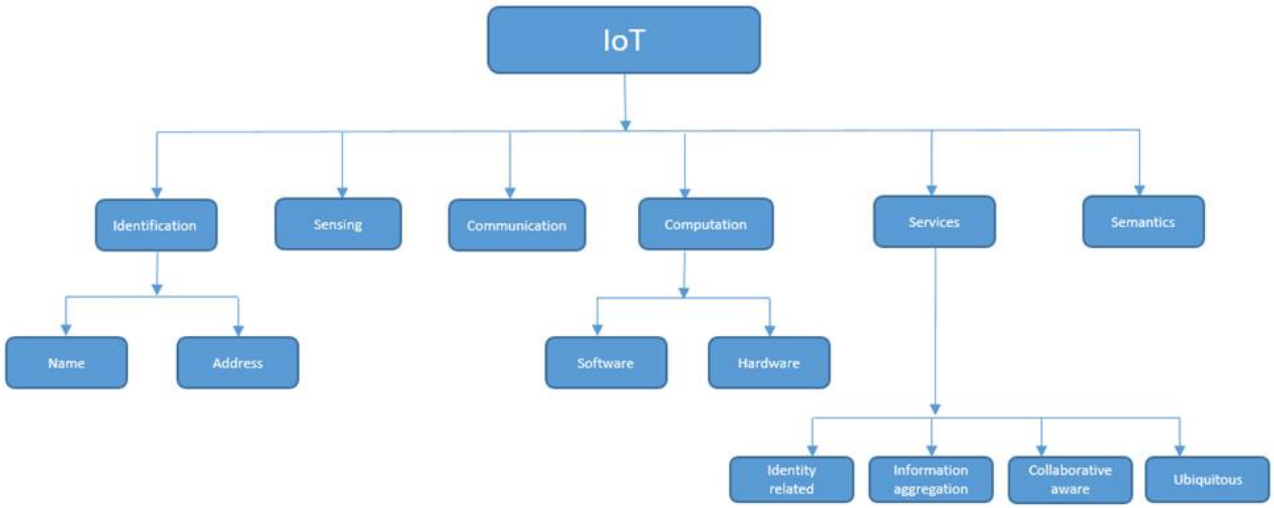

Figure 1. IoT building blocks, idea from [12]

collected data to the destination database or to the cloud. The data collected is analyzed in the cloud . Actuators, i.e. hardware mechanical devices such as switches, are also used in IoT platforms and operate in the opposite way of a sensor [12], [15], [16].

Communication block: This block contains many heterogeneous objects that exchange data and various services with each other and with the IoT platform. The communication block contains IoT communication protocols like MQTT and CoAP to connect to the objects that are connected in the IoT and to send data to the management system. The sensors and other devices are connected to the Internet by communication technologies like ZigBee, NFC, UWB, Wi-Fi, SigFox, and BLE [9], [12].

Computation block: The computation block consists of two parts, hardware and software. Many hardware platforms have been built to run IoT applications, for example, Intel Galileo, Raspberry PI, Gadgeteer, UDOO, and Arduino. Similarly, there are many software platforms that are used to perform the functionalities of IoT. The main software platform is the operating system that runs throughout almost the whole activation time of the device. The cloud platform is also a computational component of the IoT; it enable small objects to send data to the cloud, it facilitates big data processing in real time and helps the end user to obtain knowledge extracted from the big data [9], [12].

Services block: IoT services aid IoT application developers by providing a starting point for development. When developers know the services available, they mainly focus on building the application rather than designing the service and architecture for supporting the IoT application. IoT services are divided into four Categories. *Identity related* services can be divided into two categories, active and passive. Services that broadcast information and have a constant power or take power from the battery are active identity related services. Active identity related services can transmit or send information to another device. Passive identity related services have no power source and need some external device or mechanism to transmit its identity. Passive identity related services can only read information from devices. *Information aggregation* services refer to the actions of collecting data from sensors, processing that data, and transferring it to the IoT application for processing. *Collaborative aware* services use the data provided by the information aggregation services to make decisions and react accordingly. *Ubiquitous* services provide collaborative aware services anytime to anyone who needs it anywhere [15], [17], [18].

Semantic Block: IoT provides different services, for which it needs knowledge, and in order to get that knowledge in a smart way, IoT uses different machines. Knowledge extraction can include finding and using resources, modeling information, and recognizing and analyzing data to reach some decision and provide the correct service. So, it can be justifiably claimed that the semantic block is the brain of the IoT [9], [12], [15].

B. *Key Factors Of IoT Platforms*

An IoT platform is the main part of an IoT solution. There are hundreds of IoT platform vendors in the market, and finding and selecting a suitable IoT platform that is reliable and scalable is difficult. However, consideration of some key factors prior to making a platform selection decision can enable companies find and select an appropriate IoT platform for their business. The platform requirements are context-specific and it is not necessary that a platform include all the factors discussed below.

Stability: There are hundreds of IoT platforms in the market and it might be the case that not all platforms will work perfectly. Some platforms might fail to deliver services to clients. Thus, a platform should be chosen that has high chances of survival in the market. Information about the platform can be obtained from previous customers using the same platform [9].

Scalability and flexibility: Initially, a company might be small and operate in a small business area but, ideally, over time, the business will expand and with this growth, the business area will also expand. Thus, to ensure that the IoT platform can support the business throughout its development, the platform should be scalable to business needs [9]. Similarly, the platform should be flexible as regards to the technology, since modern technology and market demands change rapidly.

The pricing model and business case: Some platform providers offer a low price for a period at the start of a contract agreement, after which the price increases greatly. Additionally, some providers offer a low price to attract customers, but the contract includes limited features and additional features have a significant cost if included. Thus, a platform should be selected that offers full features for the business at a cost that suits the company's budget [9], [19].

Security: Security is an important aspect of IoT and all platforms providing IoT services should have high quality security. The security may be a device to implement cloud network security, data encryption, application authentication, secure session initiation, application authentication, cloud security, and device security (authentication and up-to-date certification) [20].

Time-to-market: When selecting an IoT platform, the questions of time-to-market and how the platform provider will support the business during the journey from product conception to sale should be considered. Some IoT platform providers offer quick-start packages for new customers, which can speed up product development, reduce time-to-market and offer better solutions [20].

Data analytics and visualization tools: Before selecting an IoT platform, prospective IoT platform users should establish which platform offers the best capabilities to aggregate, analyze and visualize data. In particular, users should consider how the IoT platform integrates leading analytics toolsets and uses them to replace built-in functionality. Data analysis and information visualization requirements should be identified before selecting an IoT platform [17].

Data ownership: A complicated issue with IoT data is ownership of the data. Different jurisdictions have different laws and legal interpretations. For example, the European union (EU) has different rules and regulations regarding data ownership than the United States (US) [21]. Therefore, it is important to have knowledge of data rights and the territorial scope of data protection for the IoT platform provider.

Ownership of cloud infrastructure: The hardware infrastructure layer is very expensive and some smaller IoT platform providers only provide the software layer. Some IoT platforms providers certify their platform on single or multiple leading public cloud providers and mostly run their services on a single leading platform. Thus, the compatibility of the broader enterprise cloud strategy with the IoT platform provider should be checked [22].

Extent of legacy architecture: The connectivity in an existing IoT is often unknown, and IoT devices are designed to work with a variety of infrastructure systems. Thus, when selecting an IoT platform, businesses should ascertain how new generations of technology can interlock with older technology [23].

Protocol: The important protocols supported by IoT platforms are MQTT, HTTP, AMQP, and CoAP. Due to its binary nature, MQTT is extremely lightweight and has much lower overheads. As a result of development in technology, new devices are coming onto the market. The selected IoT platform should support new protocols and enable easy upgrade of these protocols [27], [28].

System performance: In an IoT platform, when an event happens, a rule based trigger is invoked automatically. Since IoT platforms support rule-based triggers, as larger numbers of devices connect to the IoT platform the average time to analyze and handle each event increases. Prior to selection of an IoT platform, it should be noted what steps the provider has taken to maintain high IoT platform performance [29].

Interoperability: The IoT platform solution is a middleware. The data collected will be used by many applications and may not be available on the platform itself. Consequently, the selected IoT platform should support integration with open source ecosystems. Interoperability will enable the organization to gain higher productivity [30], [31].

Redundancy and disaster recovery: Problems sometimes occur in the IT infrastructure, either natural or man-made, and IoT platform providers should have dedicated infrastructure to handle data during such occurrences. Issues that require consideration include the data backup plan schedule and whether the IoT platform has failover cluster provision [27].

Attractive interface: The interface provided by the IoT platform should be simple, attractive and user friendly, so that it is easy for customers to use its functionalities. All the services offered to the customers should be easy to access.

Application environment: Three aspects of the application environment should be considered before selecting an IoT platform: which applications are available out of the box, what are the characteristics of the application development environment, and what are the common application interfaces [22].

Hybrid cloud: Some IoT platforms can fit with existing

IT systems hosted on company premises. In such situations, a hybrid cloud is very useful as mission critical or business sensitive processes can be handled locally, while public and less critical operations can be managed by the IoT platform [27].

Platform migration: Over time, and as the company grows, the IoT platform may be unable to meet all the company's requirements. Thus, a bigger IoT platform provider may be needed. Consequently, companies should ensure that the selected IoT platform provider provides clearly documented interfaces, schema, and API for any possible future migration to other IoT platforms [9], [27].

Previous experience: Prior to selection, a company should check whether the IoT platform provider has some experience of work similar to that of the company application. Successful working experience in the same area can be considered a good sign [20].

Bandwidth: For efficient movement of information and communication between the processing components, the IoT platform needs low latency and high bandwidth networking. Thus, it should be ascertained that a potential IoT platform provider has a large data pipe and that there is sufficient room to grow [26], [27].

Edge intelligence and control: IoT platforms are advancing at a fast rate due to high competition in technology and business markets. The future of IoT platforms is moving towards distributed, offline and edge intelligence [24]. Devices become more powerful when they are able to make decisions based on local data instead of waiting for every decision from the cloud. Thus, it should be ensured that the IoT platform has the capacity to support new topologies and utilize edge intelligence [25].

III. RESEARCH METHOD & DATA COLLECTION

A pre-study was conducted prior to the research presented in this paper to gain background information about IoT and IoT platforms. The aim of the current research is to identify key factors of IoT platforms that require consideration before IoT platform selection. The work began with a literature survey of research articles and publications related to IoT and IoT platforms published in journals, conferences and books. Twenty-six out of 200 articles were selected for study. The databases used in this research are IEEE, ACM and SCOPUS. Google Scholar is also used for some topics and some selected websites reviewed and referenced.

The Delphi method is used in the main part of this study. In this work, 15 professionals participated in the Delphi study, which was conducted in two rounds. In the first round, a questionnaire comprising twenty-one questions was sent to the participants by email through a survey link. A 5-point rating scale was used: 1) totally disagree, 2) disagree, 3) neutral, 4) agree, and 5) totally agree. Fourteen participants responded in the first round. One reply was removed because it included no information about the respondent. The results of the first round were calculated, and based on the first round results, the second round questionnaire was constructed and sent to individual participants. Twenty-one (21) important factors were identified from the literature. These factors were then verified by the Delphi method and categorized.

IV. DELPHI STUDY

The Delphi method is an accepted and widely used method for canvassing opinions from a limited number of experts or professionals, from 10 to 18, operating in the same field [32], [33]. Delphi method is an iterative process, there are series of rounds and each round has some output, the output of one round is the input of the next round until the result is obtained. Two rounds of Delphi process are preferred when extensive literature is available and the aim is to get experts' opinions about the subject [34].

Delphi methods, as shown in Fig 2 is used in this research consists of two rounds. During the first round, fifteen IoT experts from three different universities were recruited, based on their experience in IoT field. A questionnaire comprising twenty-one (21) questions was sent by email to the experts through a link. Fourteen experts replied, giving a response rate of 93% . The experts' opinions of the first round of Delphi study are shown in Fig 3. Most of the experts opinions were in favor of first round questions. The experts' opinions in the first round of the Delphi study were noted. Based on the first round opinions, individual questionnaires on the second round of the Delphi study were designed and sent to the concerned experts along with the summary of experts' opinions of first round results either by email or on paper.

In the second round of the Delphi study, some experts changed their opinions about some questions based on the summary of experts' opinions of the first round. The second round opinions are shown in Fig 4. The final results of both rounds are shown in Fig 5.

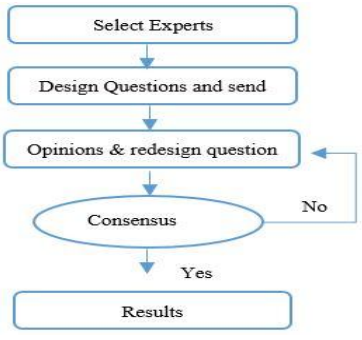

Figure 2. Delphi method.

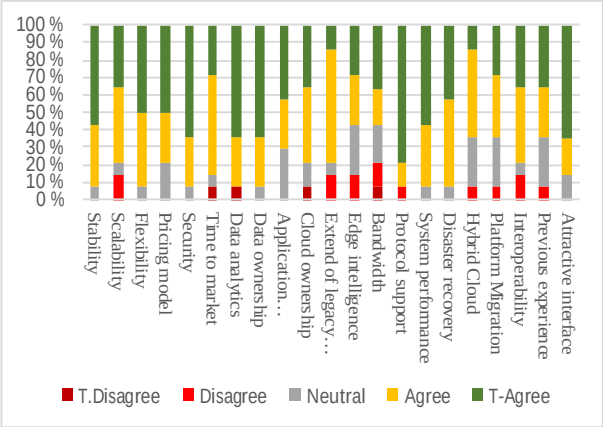

Figure 3. Expert opinion in the first round.

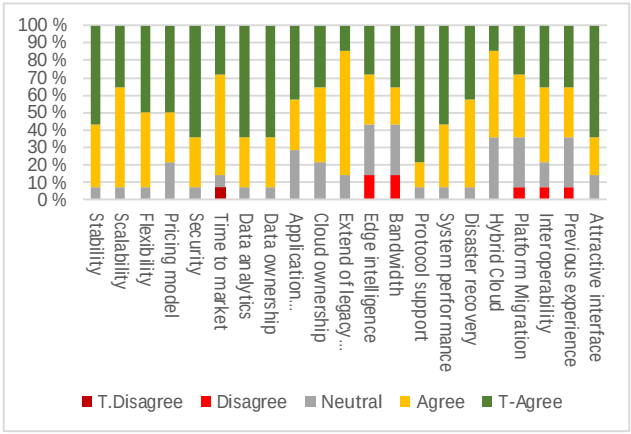

Figure 4. Expert opinion in the second round.

		Round 1					Final Round				
Sno	Topic	Mean	Median	Dis agree %	Neutral %	Agree %	Mean	Median	Dis agree %	Neutral %	Agree %
1	Scalability	4	4	14 %	7 %	79 %	4	4	0 %	7 %	93 %
2	Flexibility	4	4,5	0 %	7 %	93 %	4	4,5	0 %	7 %	93 %
3	Data analytics	4	5	7 %	0 %	93 %	5	5	0 %	7 %	93 %
4	Disaster recovery	4	4	0 %	7 %	93 %	4	4	0 %	7 %	93 %
5	Stability	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
6	Security	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
7	Data ownership	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
8	Protocol support	5	5	7 %	0 %	93 %	5	5	0 %	7 %	93 %
9	System performance	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
10	Time to market	4	4	7 %	7 %	86 %	4	4	7 %	7 %	86 %
11	Extend of legacy architecture	4	4	14 %	7 %	79 %	4	4	0 %	14 %	86 %
12	Attractive interface	5	5	0 %	14 %	86 %	5	5	0 %	14 %	86 %
13	Pricing model	4	4,5	0 %	21 %	79 %	4	4,5	0 %	21 %	79 %
14	Cloud ownership	4	4	7 %	14 %	79 %	4	4	0 %	21 %	79 %
15	Interoperability	4	4	14 %	7 %	79 %	4	4	7 %	14 %	79 %
16	Application environment	4	4	0 %	29 %	71 %	4	4	0 %	29 %	71 %
17	Hybrid Cloud	4	4	7 %	29 %	64 %	4	4	0 %	36 %	64 %
18	Platform Migration	4	4	7 %	29 %	64 %	4	4	7 %	29 %	64 %
19	Previous experience	4	4	7 %	29 %	64 %	4	4	7 %	29 %	64 %
20	Edge intelligence	4	4	14 %	29 %	57 %	4	4	14 %	29 %	57 %
21	Bandwidth	4	4	21 %	21 %	57 %	4	4	14 %	29 %	57 %
	Percentage			**6 %**	**14 %**	**80 %**			**4 %**	**15 %**	**81 %**

Figure 5. Results of the Delphi study

In the first round, agreed percentage is 80%, disagree percentage is 6% and neutral percentage is 14%. In the second round, agreed percentage increased to 81%, disagree percentage dropped down to 4% and neutral percentage increased to 15%. The importance of all the twenty-one factors of IoT platform are categorize into three categories in the light of experts' opinions. Factors with agreed percentage up-to 79% and above are considered very important, factors with agreed percentage between 78% and 64% are considered somehow important, and factors with agree percentage less than 60 % are considered as less important. According to experts opinions factors i.e. *stability, security, protocol support, system performance, disaster recovery, data analytics, scalability, flexibility, data ownership, extend of legacy* architecture, pricing model, *interoperability, attractive interface, cloud ownership, time to market* were considered as the most important factors and according to the experts opinions four factors i.e. *application environment, hybrid cloud, platform migration, previous experience* were considered as somehow important and two factors i.e. *edge intelligence and bandwidth* were considered as less important.

V. DISCUSSION & CONCLUSION

The aim of this study was to identify important factors of an IoT platform from the literature and facilitate companies in selection of suitable platform that can solve the needs of IoT application. We identified twenty-one IoT platform factors from literature, Delphi method was used to verify those factors through the expert's opinions. Fifteen experts from three universities were selected based on experience in IoT field. The identified twenty-one IoT platform factors were divided into three categories based on expert's opinions.

In this study, we have identified and explained most of IoT platform important factors that should be considered before selection of an IoT platform for IoT application. Comparing this study with recent studies in literature, we have noticed that similar study has been done by [9] in which the authors have mentioned few IoT platform factors like stability, scalability and flexibility and pricing model of the business case. Another study [35] highlighted the importance of data security. During another study [36] the authors claim that IoT platform should support integration with open source ecosystem and considered interoperability as important factor for IoT platform. The selected recent studies in literature have targeted few specific important factors about IoT platforms. The current study mainly focused to identify most of the important IoT platform factors and verify those factors, based on expert's opinions using Delphi method. Based on the expert's opinions using the Delphi method, we believe there are many important IoT

platform factors that should be considered before selecting a suitable IoT platform for IoT application.

The challenges the companies are facing in selection of IoT platform, are quite common due to advancements in technology. We believe company can select an appropriate IoT platform for their IoT application, if they first analyze their business requirements, and start selection of the IoT platform with clear business requirements and have the knowledge of key factors of IoT platforms.

This study highlighted important key factors of IoT platform. Those key factors may cover some of the current requirements of the companies and can help ensure that future needs of the business are meet. It will facilitate the companies to select a suitable IoT platform for their business needs.

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