Initiatives towards the cross-domain interoperability of Smart Devices

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ABSTRACT

Smart devices, enabled with internet connectivity and computing capabilities, collect data and interact with their environment. These IoT devices offer increased functionality and convenience, from household appliances to industrial sensors. Technological advancements, cost reductions, and the demand for efficiency and security drive their popularity. The global IoT market is projected to grow significantly, especially with the rise of smart homes, 5G networks, and IoT adoption in sectors like healthcare and manufacturing. Interoperability, crucial for seamless operation of diverse smart devices, faces challenges including fragmented standards, security risks, technical complexity, and conflicting market incentives. Efforts to address these challenges involve industry-wide standards, open-source platforms, and secure communication protocols. However, ensuring interoperability among diverse devices presents significant challenges:

1. Fragmented standards: The rapid growth of IoT has led to the proliferation of standards, protocols, and technologies, hindering interoperability efforts.

2. Security and privacy: Interoperability increases vulnerability to cyber threats, raising concerns about security and privacy.

3. Technical complexity: Achieving interoperability is technically complex and requires substantial time and resources, compounded by compatibility issues and lack of standardization.

4. Market incentives: Conflicting interests among manufacturers make it difficult to establish common standards and protocols.

Despite these challenges, ongoing efforts aim to enhance interoperability through industry-wide standards, open-source platforms, and secure communication protocols. By addressing these challenges, the potential benefits of interoperability can be realized, leading to a more connected and seamless IoT ecosystem. This paper reviews recent IoT protocols and standardization developments, focusing on interoperability.

Keywords: IoT, Smart Devices, Interoperability, IoT Protocols

1. Introduction

The Internet of Things (IoT) revolutionizes the way physical objects and devices communicate, connecting them to the Internet and enabling seamless interactions. This concept, coined by Kevin Ashton in 1999 [1], has rapidly transformed various sectors. IoT has framed usual businesses. It has linked together the real and electronic worlds [2], As shown in figure 01 IoT integrates real-world entities such as users, gadgets, sensors, actuators, and data resources into a cohesive network, making interoperability crucial for effective communication [3].

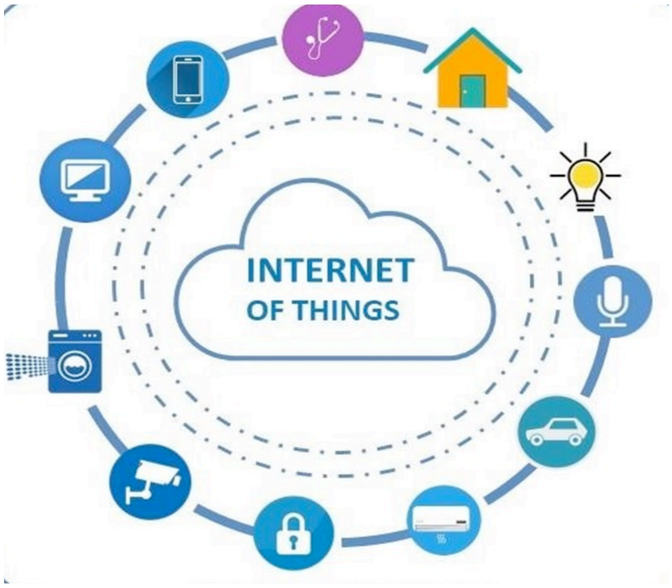

Figure.1 Internet of Things

Several different entities are actively working to enhance the interoperable protocol and open standards for IoT. It is a transition from the HTTP, TCP/IP stack to the IoT-specific protocol.
The number of possible IoT solutions per domain is growing promptly, but so is their machinery footprint:
Even if the designs complicated are deteriorating in size, their variety is growing as to a greater extent requests and services address the various facets of the trade and personal growth [4].
According to the European Research Cluster on the Internet of Things (IERC), IoT is defined as an active global network foundation accompanying self-configuring proficiencies established patterned and interoperable communication contracts, at which point tangible and virtual belongings have and use identities, physical attributes, and virtual traits smart interfaces and are seamlessly joined into the information network [5].
However, the evolution of IoT has led to a proliferation of diverse platforms and solutions. While companies like Cisco, Microsoft, IBM, Google, ThingsBoard, and Oracle are actively contributing to IoT advancements, the absence of standardization and interoperability poses significant challenges [6]. With over 400 IoT platform providers offering a multitude of services, each with its framework and interfaces, achieving seamless communication between devices has become imperative [7].
From the view of IoT providers, the lack of interoperability resources that service providers are accountable and obey an alone wage earners IoT device or spreadsheet, that concede possibility entail the potential risk of later taller functional costs in addition to output functionality and support issues [8].
From the view of request developers, the inconsistency between IoT platforms leads to their request being adjusted to the platform-particular API and information models of each different principle, which demands a cross-platform, i.e.. Applications are active on diversified platforms and cross-rule use development.
Inter-Operate means that one system can perform operations on another system. It provides services where heterogeneous computer systems can perform the operations together and grant access to their resources. In the Cambridge dictionary, interoperability is defined as “the degree to which two products, programs, etc. can be used together or the quality of the ability to be used together” [10].
The IEEE Standard Computer Dictionary defines interoperability as “the ability of two or more systems or

components to exchange information and use the information exchanged" [11].
A lack of interoperability leads to significant limitations on a technical and business level. It also makes it impossible for device integrations. The goal of IoT is achieved with the standardization of device communication, resource sharing, process management, and programming in heterogeneous devices from different manufacturers. For elementary ideas to take place, a consumer or instrument needs a habit of searching for belongings and approaching the info they produce. This requires an understanding of many fundamental conversation issues, such as circumstances granted, looked for, and made approachable connected to the internet [12].
In this context, the research problem this paper addresses is the pressing need for addressing the interoperability challenges within the rapidly expanding IoT domain. The diverse platforms and interfaces offered by numerous IoT providers create a fragmented landscape, hindering seamless communication and integration. This paper aims to delve into these challenges, exploring solutions and strategies that can establish interoperability standards in the IoT sector. By defining the scope of these interoperability challenges, this study seeks to provide valuable insights into the development of a more connected and cohesive IoT ecosystem.

2. Levels of Interoperability

A categorization of interoperability for IoT has established four layers: technical, syntactic, semantic, and organizational interoperability [13].

1. Technical Interoperability

It refers to the technical features of interoperability such as broadcast agreements and info exchange formats. Lack of compatibility still creates hurdles in the development of IoT. It covers wide aspects of interconnection services, data integration services, data exchange and presentation, communication protocols, and interface specifications.

2. Syntactic Interoperability

Syntactic interoperability refers to the process in which data is communicated between devices. The data structure and format are used in the exchange of information. It is the strength to right learn or define the layout and building of the exchanged data and thus, of being smart to interpret and use its content.
IoT merchants utilize uniform and established technologies and standards to increase the acceptance of their devices. Popular solutions include the messaging rules CoAP, XMPP, AMQP, MQTT, DDS, and Hy-LP, as well as the platforms DPWS, UPnP, and OSGi [14]. Syntactic Interoperability can be improved by standardizing the data formats and mode of communication.

3. Semantic Interoperability

Semantic interoperability uses controlled vocabulary to ensure that data is exchanged without losing its meaning. It's a set of techniques that enables computing devices to communicate precisely. It creates the possibility to lead down the integration cost of sub-devices and it also plays a vital role in the creation of an autonomous operation in IoT. Semantic interoperability includes the ability to establish a common meaning for the data exchanged and the ability to interpret communication interfaces similarly.
The most notable efforts towards these goals in the IoT space are the World Wide Web Consortium (W3C) community's Semantic Sensor Network (SSN) and Sensor Observation Sampling Actuator (SOSA) ontologies [15].

4. Organizational Interoperability

Organizational interoperability states the system-based organization where heterogeneous devices can communicate effectively and properly transfer information. For the achievement of this, the organization must ensure the proper technical, syntactical, and semantical interoperability between devices [16]. Figure 02 represents organizational interoperability.

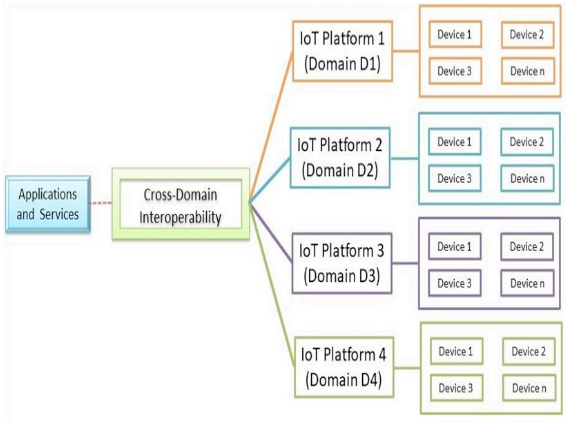

Figure. 2 Organizational Interoperability

3. Related Initiatives

Many different initiatives have been proposed by researchers in the past to overcome the interoperability problem of IoT devices.

3.1 BIG-IoT (Bridging the Interoperability Gap of the IoT)
BIG-IoT is a project aimed at developing cross-platform, cross-standard, and cross-domain IoT services and applications to build an IoT ecosystem [17].
BIG IoT supports three main keys:
(1) A common BIG IoT API,
(2) well-defined information models, and
(3) a marketplace to monetize access to resources.
BIG-IoT provides a common platform, allowing different IoT platforms to access and coordinate exchanges of sensors, data, and services through a common BIG-IoT API and underlying marketplace [18].

3.2 INTER-IoT
The INTER-IoT project provides services to connect and collaborate with various manufacturers and developers by providing superior service and providing a superior experience to succeed without competing with anyone [19].
In the absence of a global IoT standard, the INTER-IoT achievement will enable any company to design and develop new IoT devices or services, leverage existing ecosystems, and bring them to market quickly [20].

3.3 VICINITY (Open Virtual Neighbourhood Network to Connect IoT Infrastructures and Smart Objects)
The VICINITY project aims to develop a bottom-up IoT ecosystem with decentralization of interoperability, called a virtual neighborhood. The concept of a virtual neighborhood is to grant access to smart objects without losing user control. It's a kind of social network where the sharing of devices and data is under the control of its owner [21].
VICINITY is focused on platforms and ecosystems that provide interoperability as a service for the infrastructure of the IoT and accommodate other layers of the IoT architecture [22].

3.4 SymbIoTe (symbiosis of smart objects across IoT environments)
It develops an interoperability platform that provides platforms for vertically isolated devices. Provide the capabilities of Unified IoT Resources Discovery and Access to the closed environment of the IoT Platform, wishing to collaborate directly with others without an intermediary, and provide an IoT Platform Federation where the platform can collaborate according to signed terms and conditions [23].
symbIoTe breaks down the strict separation between IoT islands to create an environment that:
1. It bridges individual efforts and investments, and therefore has a significant impact on the market,
2. attractive to heterogeneous user groups,
3. through lightness, the dynamism of modern life meets the purpose and
4. useful for a variety of business, private, and public infrastructure use cases.

5. AGILE (An Adaptive and Modular Gateway for the IoT)

AGILE builds modular, adaptive gateways for IoT devices. The hardware layer of modularity provides support for a variety of wireless and wired IoT network technologies, while the software layer of modularity provides new capabilities for data collection and management at the gateway, intuitive for device management with various components. The intuitive user interface enables a visual workflow editor. Building his IoT App and IoT Marketplace for local installation of IoT apps [24].

This project considers all the modules required for a robust safety management system. The AGILE project focuses on technical and syntactic interoperability at the hardware and software levels [25].

Additionally, organizational interoperability is achieved and all other interoperability layers are properly considered. In this context, BiG-IoT creates a common and generic application programming interface (API) across different IoT middleware platforms. Open-IoT implements a cloud-based middleware platform with innovative tools and capabilities. In addition, the VICINITY project will create a framework with many modules and tools that follow the interoperability-as-a-service philosophy for the "Internet of Things Nearby". Additionally, the INTER IoT Platform will increase the level of interoperability for organizations with INTER APIs. This includes multiple interoperability tools at each level.

4. Conclusions

The Internet of Things (IoT) marks a significant evolution in the realm of the Internet, presenting both challenges and opportunities that demand careful consideration for successful implementation. The current landscape of the IoT market is characterized by fierce competition among manufacturers vying for dominance. Interoperability, the seamless interaction between smart devices, is pivotal to overcoming limitations and propelling the IoT forward.

Addressing interoperability issues at all stages of IoT development is paramount. Users, in their interactions with IoT devices, encounter the need to navigate various applications, necessitating a unified approach. Bringing diverse technologies together is essential to bridge the interoperability gap among smart devices.

This study delves into key aspects of IoT device interoperability standards and illuminates ongoing initiatives in this realm. Embracing this heterogeneity while fostering standardized communication channels is pivotal for the sustainable growth and effectiveness of the IoT landscape. The whole conclusion is to accept the heterogeneity of IoT devices and establish common standards for secure communication and connection.

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