Smart City Insights

www.sci.reapress.com

Smart City Ins. Vol. 1, No. 1 (2024) 57–62.

Paper Type: Original Article

A Short Note on Lack of Interoperability in the Internet of Things

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Citation:

Received: 6 October 2023 *Revised: 2 November 2023* *Accepted: 4 March 2024*	Pattanaik, S., Acharya, A., Mishra, M., sagar, A., & Mishra, M. (2024). A short note on lack of interoperability in the Internet of Things. *Management analytics and social insights*, *1*(1), 57-62.

Abstract

The Internet of Things (IoT) promises a world where devices seamlessly communicate, enhancing convenience, efficiency, and innovation. However, this vision is hampered by a significant challenge: the lack of interoperability. Interoperability refers to the ability of different IoT devices and systems to work together smoothly, regardless of manufacturer or protocol. Currently, diverse standards, protocols, and platforms create silos, preventing seamless integration. This fragmentation leads to inefficiencies, increased costs, and security vulnerabilities. Addressing this issue requires developing and adopting universal standards, fostering stakeholder collaboration, and encouraging an open ecosystem. Solving interoperability challenges is crucial for realizing the full potential of IoT, enabling smarter cities, improved healthcare, and more efficient industries.

Keywords: Internet of things, Semantic web technologies, Semantic interoperability, Heterogeneous data, Linked data.

1 | Introduction

Interconnected Internet of Things (IoT) devices, such as sensors and smart objects, are heterogeneous. They collect and transmit large amounts of IoT raw data through the Web. The convergence of information and communication technologies has resulted in the exponential proliferation of data, which is expected to rise further as the use of IoT devices expands [1]. Hence, a high level of complexity due to a large number of heterogeneous objects, raw datasets, and services makes heterogeneity unavoidable. The IoT concept implies that all devices are harmoniously connected to communicate and readily accessible from the internet to provide services to applications and end-users [2]. Due to the interest and massive amount of IoT raw data available on the web and the considerable number of interconnected devices, scalability, heterogeneity, and interoperability issues arise [3]. It creates a multitude of problems that are considered a significant obstacle to

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the vision of IoT and its full implementation and deployment in our daily lives. It is necessary to develop formal semantic representations and technologies to enable interoperability between heterogeneous devices [4]. It implies that interoperability between IoT "things" is one of the most fundamental requirements for supporting knowledge representation, discovery, and exchange. These latter use technologies inherent to the semantic web group, such as ontologies, web services, semantic annotations, and reasoning. They aim to provide a semantic framework that addresses issues of heterogeneity and interoperability in cross-domain applications [5].

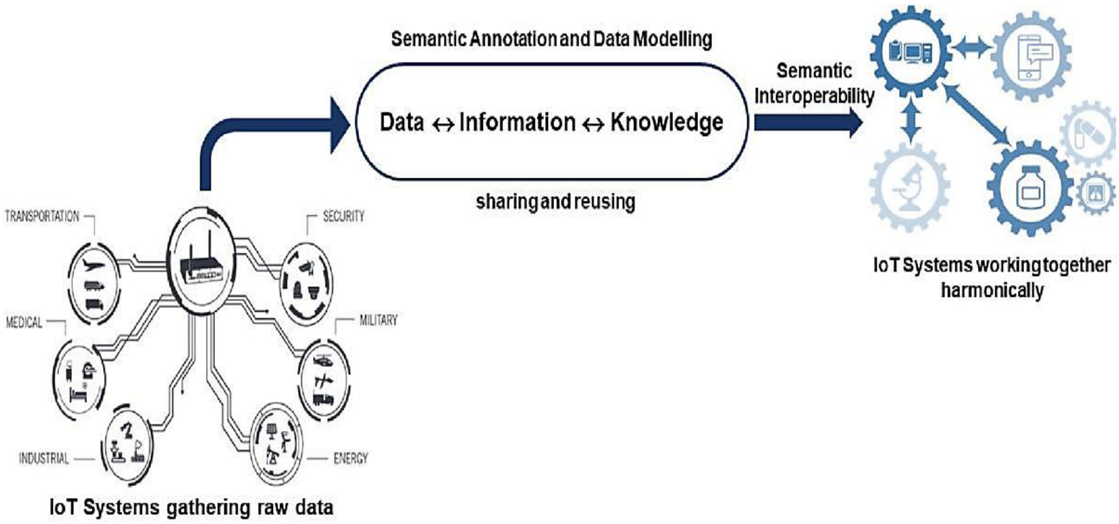

Fig. 1. IoT systems raw data gathering.

2 | Literature Review

Interoperability refers to the ability of different IoT devices, applications, and platforms to exchange and interpret data seamlessly. It ensures that devices from various manufacturers can work together effectively, enabling users to create comprehensive and interconnected systems. However, achieving interoperability in the IoT landscape poses several challenges that must be addressed. IoT data heterogeneity necessitates producing uniform and machine-understandable data that any application can easily process. The data collected from different IoT sources are based on various data models [6]. A semantic-based approach can be adapted to enable standard representation, sharing and inferring new knowledge from this heterogeneous data [7]. Semantic web technologies are one of the most prominent methods to eradicate data heterogeneity and produce machine-interpretable data that enables data interoperability. To solve the heterogeneity problem, using the core of semantic technology (ontology) to semantic annotation for the information of things can provide machines with more understandable information [8]. The term "ontology", derived from philosophy, is defined as a formal description of knowledge in computer science. An ontology offers a unique perspective on the world or its part, specifying what concepts to represent and how they are related to producing knowledge artefacts.

Many IoT-related technologies have been increasingly designed and deployed to collect a large amount of heterogeneous data to monitor environmental phenomena. Despite its relevance, the IoT's ongoing progress has resulted in an increasingly high level of complexity. This is mainly due to a large number of diverse installed equipment, sensing data, and recommended services. Consequently, interoperability and heterogeneity issues have been raised. To overcome this, semantic web technologies are employed as an appropriate solution for harmonizing data and handling semantic interoperability throughout the IoT systems and services [9]. To achieve the semantic web approach, several components, such as languages and knowledge representation formalisms, have been identified through various research works. They were created by the World Wide Web Consortium (W3C) within the semantic web framework. The semantic web stack is an illustration of the language hierarchy. It demonstrates how standardized semantic web technologies are organized to enable the semantic web vision *Fig. 1*. Data must be uniquely identified, which is accomplished through a Uniform Resource Identifier (URI) or Internationalized Resource Identifier (IRI).

I. Resource Description Framework (RDF) Is the first W3C standard for publishing and linking data to enrich web resources. It offers a mechanism for describing things using a triple RDF (subject, predicate, object) that establishes a link between its identifier and other web resources. Data on the web must be interpreted in conjunction with other data. RDF is a graph model that uses triples to describe web resources formally, and their metadata assists us in defining data about other data. Combining many triples provides what is known as an RDF graph.

II. RDF Schema (RDFS) provides a vocabulary for data modelling with RDF data. It allows for a higher level of abstraction. Its goal is to specify metadata schemas. It defines a set of properties' meaning, characteristics, and relationships. The advantage of RDFS is that it facilitates data inference and strengthens research on that data.

III. Ontology Web Language (OWL) allows for representing complex knowledge and interrelationships. It defines resources or objects and their relationships to describe and represent a specific knowledge domain. However, it is also used to determine individuals and assert their properties. OWL defines ontologies by using the RDF/XML syntax to expand the vocabulary and properties of RDF and RDFS. It allows for greater freedom in expressing relationships. OWL has three increasingly expressive sublanguages: OWL Lite, OWL DL, and OWL Full, which use all OWL language's functionalities and offer varying degrees of expressiveness [10].

IV. SPARQL protocol and RDF Query Language (SPARQL) [34] SPARQL is a standardized query language published by the W3C in 2013, which is the equivalent of SQL for RDF graphs and is based on RDF triples to process data on the web. It is a query language and protocol that uses a set of queries to search, add, modify, or delete IoT data stored in RDF triples.

V. Semantic Web Rule Language (SWRL) [39] combines Ontologies and rules and is a standard language built on OWL-DL and the Rule Markup Language (RuleML). SWRL expresses rules for reasoning and inferring new knowledge from an existing web-based IoT data description. Adding supplementary predicates enhances the RDF triples and allows IoT applications to obtain more precise information and make better decisions.

The semantic IoT framework is a collection of layers for data aggregation, persistence, analytics, and serving. semantic web framework enables the integration of heterogeneous data within the same structure and transparent access to applications that can fall back on the data collected for their specific purpose. In the following, we present existing IoT-relevant frameworks that support semantic interoperability in IoT systems, such as BiG-IoT, FIESTA IoT, VICINITY, INTER-IoT, Open-IoT SymbIoTe, and the M3 framework.

3 | Proposed Study

Big-IoT: BiG-IoT developing the BiG-IoT API relies on semantic addressing and IoT interoperability issues to realize real IoT ecosystems. The project is a web platform that connects various platforms and middleware systems. It makes use of schema.org as a concept vocabulary. With a well-defined API and architecture, creating applications and services for heterogeneous platforms with increasing semantic interoperability is simple. As presented in, the following functions frame the IoT API:

I. Identity management for registering resources.

II. Discover resources according to user-defined search criteria.

III. Access metadata and data (download data and publish/record feeds).

IV. Vocabulary management for semantic descriptions of concepts.

V. Security, including identity management, authorization, and key management.

VI. Billing allows you to make money through payment and billing mechanisms.

FIESTA: IoT federated interoperable semantic IoT testbeds and applications. It is a Horizon 2020 research project and an innovation action funded by the European union. It treats the topic of "future internet research and experimentation". The project consists of large-scale IoT experiments using data and resources from disparate IoT platforms [2]. With semantic technologies, the FIESTA project enables researchers and experimenters to share and reuse data from various IoT testbeds. These experiments offer a variety of tools and best practices for enhancing the interoperability of heterogeneous IoT platforms. The FIESTA-IoT architecture is a set of functional blocks allowing:

I. Testbed data streams and resources to be plugged into FIESTA-IoT.

II. Be discoverable using FIESTA-IoT and be accessible via FIESTA-IoT services.

III. Semantic querying linked data sets (of collected testbed data) and IoT service APIs.

IV. Secure access to testbed resources by authenticated and authorized experimenters.

M3 framework: machine-to-machine measurement framework enables IoT applications, assists users in interpreting sensor measurements, and combines domains. M2M is used in the project's framework to annotate semantically and reason about M2M data collected from various IoT devices, systems, and domains. The following layers frame the M3 framework to increase the level of interoperability at the syntactic, but especially at the semantic level.

I. The perception layer comprises physical IoT devices like sensors, actuators, and smart objects.

II. The data acquisition layer collects raw data from IoT devices and converts it into a unified format, such as RDF/XML, compliant with the M3 ontology.

III. The persistence layer is responsible for storing M3 in a database to store semantic sensor data, referred to as the triple store.

IV. To update M3 domain ontologies, datasets, and rules, the knowledge management layer is responsible for finding, indexing, designing, reusing, and combining domain-specific knowledge, such as ontologies and datasets.

V. Reasoning layer that uses reasoning engines and M3 rules to infer new knowledge.

VI. The knowledge query layer executes SPARQL (an SQL-like language) queries on inferred sensor data.

VII. The application layer uses an application (which runs on smart devices) to parse and display the results to end users.

IoT applications domains make use of semantic: IoT combines many existing technologies, including communication network technologies, information technologies, sensing/control technologies, software technologies, and hardware/device technologies, to improve operations, lower costs, create new products and business models, and improve engagement and customer experience. IoT applications and services will cover many aspects of our daily lives, including energy management, inventory management, traffic management, home control and automation, industrial automation, healthcare, the battlefield, and many others. An explosion of IoT devices and platforms has been integrated into a wide range of applications, including industry, hospitals, agriculture, infrastructure, electricity, transportation, industrial control, and homes, among others. Thus, a profound upheaval has been produced in all areas. Semantic notifications allow deep data analysis and knowledge discovery, especially in activity recognition, decision-making, and trend discovery. It provides easy access and interaction with various smart physical devices and high-performance objects. Then, it facilitates the development of innovative smart applications in many fields, such as smart cities, smart homes, smart health, and smart agriculture. As for now, some applications are being developed that integrate semantics into IoT applications in several areas. In this section, we present important application domains of IoT using semantics, in which we take up some examples of recent work in different technology areas and their main contributions.

4 | Conclusion

In conclusion, the lack of interoperability in the IoT is a critical barrier to unlocking its full potential. This fragmentation across standards, protocols, and platforms hinders seamless communication between devices, resulting in inefficiencies, higher costs, and increased security risks. To overcome these challenges, it is essential to develop and adopt universal standards, promote collaboration among industry stakeholders, and encourage the creation of an open ecosystem. By addressing interoperability issues, we can pave the way for smarter cities, enhanced healthcare, and more efficient industrial processes, ultimately realizing the transformative promise of IoT.

Author Contributions

conceptualization, S. P. and A. A.; methodology, A. A.; software, S. M. and A. S; validation, M. M., A. P. and M.M.; formal analysis, A. A.; writing-original draft preparation. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Data Availability

All the data are available in this paper.

Conflicts of Interest

The authordeclare no conflict of interest.

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