The Internet of Things: Architecture, Communication Protocols, and Applications

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ABSTRACT

The Internet of Things connects large numbers of physical objects, embedded with sensors and communication, to networks and to one another, and this paper reviews its architecture, communication protocols, and applications. It describes the layered architecture of an Internet-of-Things system: a perception layer of sensors and actuators that interacts with the physical world; a network layer that provides connectivity and carries data; an edge or fog layer that processes data near its source; and an application layer that provides analytics and services, commonly in the cloud. It describes the communication technologies, distinguishing the radio and network technologies that carry the data, from short-range technologies to wide-area low-power and cellular networks, from the messaging protocols that structure the data, such as the lightweight publish-subscribe and constrained application protocols. It describes the processing of data at the edge, including the running of machine learning on constrained devices, and surveys the principal application domains, including the smart home, the smart city, industrial systems, healthcare, agriculture, and transportation. The study finds that the Internet of Things provides a flexible architecture for connecting the physical and digital worlds, that its communication protocols are chosen to suit the constraints of devices and networks, and that it faces significant challenges of security, interoperability, and scale. It notes that specific technologies and standards are representative of a rapidly evolving field. It concludes with the outlook for the field. Certain figures are illustrative.

KEYWORDS: *Internet of Things, IoT Architecture, Edge Computing, MQTT, CoAP, LPWAN, Wireless Sensor Networks, Smart Systems, IoT Security*

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INTRODUCTION

The Internet of Things is the extension of network connectivity to large numbers of physical objects, from sensors and household appliances to industrial machines and vehicles, which are embedded with the means to sense, communicate, and sometimes act, and which exchange data with one another and with networked services. By connecting the physical and digital worlds on a vast scale, the Internet of Things enables the monitoring, control, and automation of processes across many domains, and it has become one of the most significant developments in information technology. This paper reviews its architecture, communication protocols, and applications [1], [2].

An Internet-of-Things system is commonly organised in layers. A perception, or sensing, layer of sensors, actuators, and embedded devices interacts with the physical world, sensing its state and acting upon it. A network, or communication, layer provides connectivity and carries the data, using a variety of radio and network technologies and messaging protocols. An edge, or fog, layer processes data near its source, reducing the delay and the volume of data sent onward. And an application layer, commonly in the cloud, provides the analytics, services, and interfaces through which the data are used. This layered architecture organises the components of a system and their interaction [1], [3].

The communication of an Internet-of-Things system involves two distinct choices: the radio and network technology that carries the data, and the messaging protocol that structures it. The central purpose of this paper is to review the architecture, these communication technologies and protocols, the processing of data at the edge, and the application domains of the Internet of Things, together with its principal challenges. The paper draws on the established and current literature, notes that specific technologies and standards are representative of a rapidly evolving field, and notes that certain figures are illustrative.

LITERATURE REVIEW

The architecture of Internet-of-Things systems is described in the literature [1], [2], [4]. The layered model organises a system into a perception layer, which senses and acts on the physical world through sensors and actuators; a network layer, which provides connectivity and transports data; and an application layer, which delivers services and analytics; and this

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classic three-layer model is commonly extended with an edge or fog layer that processes data close to its source. The layers interact, data flowing upward from the sensors to the application and control flowing downward, and the architecture provides a framework within which the many components of a system, devices, gateways, networks, and services, are organised. The literature describes variants of this model and the roles of the layers [1], [3].

The communication technologies and protocols of the Internet of Things are described in the literature [5], [6], [7]. The radio and network technologies that carry the data range from short-range technologies, such as low-power Bluetooth, Zigbee, and wireless local networks, and mesh technologies for the home, to wide-area technologies, including low-power wide-area networks such as long-range and narrowband cellular technologies, chosen according to range, power, data rate, and mobility. Distinct from these are the messaging protocols that structure the data: the lightweight publish-subscribe protocol widely used for telemetry, which suits constrained devices and unreliable links; the constrained application protocol, a lightweight protocol for very constrained devices; and others used for enterprise and web integration. The literature emphasises that the radio and the messaging protocol are chosen separately and that the choice depends on the requirements of the application [5], [6].

The processing of data, the applications, and the challenges of the Internet of Things are treated in the literature [8], [9], [10]. Processing may be performed in the cloud or, increasingly, at the edge, near the source of the data, reducing latency and the volume of data transmitted and improving privacy; and machine learning is increasingly performed on constrained devices themselves, a development supported by specialised frameworks. The applications of the Internet of Things span many domains, including the smart home, the smart city, industrial systems, healthcare, agriculture, and transportation, each using the sensing, communication, and processing of the Internet of Things to monitor and automate processes. The literature also emphasises the challenges: the constraints of devices in power, memory, and processing; the security and privacy of systems with many, often weak, devices; the interoperability of heterogeneous devices and standards; and the scalability of systems with vast numbers of devices. These considerations frame the present review [8], [9], [10].

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RESEARCH GAP

The architecture, communication protocols, applications, and challenges of the Internet of Things are treated in specialised literatures, but a concise, integrated account that presents the layered architecture together with the communication technologies and protocols, the processing of data, and the application domains, and that notes the principal challenges, is useful for orientation. There is therefore value in a consolidated review that connects these elements and situates them within the field as a whole.

OBJECTIVES

The specific objectives of this study are:

- To describe the layered architecture of an Internet-of-Things system.
- To describe the radio and network technologies that carry data.
- To describe the messaging protocols that structure the data.
- To describe edge processing and the principal application domains.
- To note the principal challenges of security, interoperability, and scale.

METHODOLOGY

A review-based approach was adopted. The architecture, communication technologies and protocols, and applications of the Internet of Things were consolidated from the established and current literature [1]-[10], and the material was organised into a framework comprising the layered architecture, the communication technologies, and the application domains. Where figures present the architecture, the technologies, or the application domains, these are illustrative and schematic, intended to convey structure rather than exact configurations, and the technologies and standards named are representative of a rapidly evolving field.

Architecture and Communication

The layered architecture of an Internet-of-Things system is represented in Figure 1, showing the perception, network, edge, and application layers and their interaction. The communication technologies are represented in Figure 2, positioning short-range and wide-area technologies by their range and data rate. These representations organise the architecture and communication as set out in the literature [1], [5].

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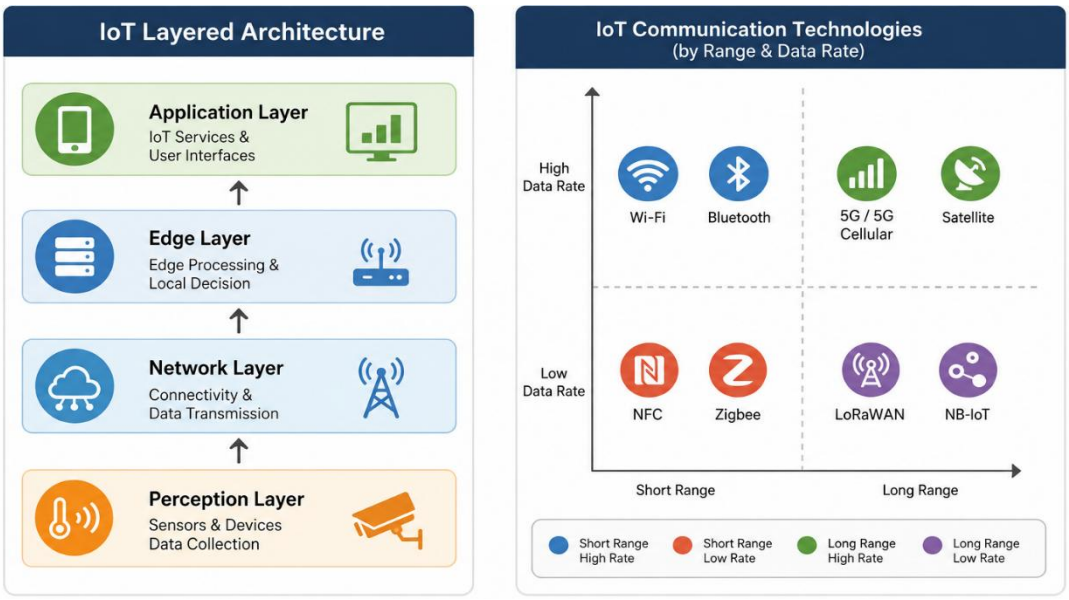


Figure 1: A layered architecture of the Internet of Things

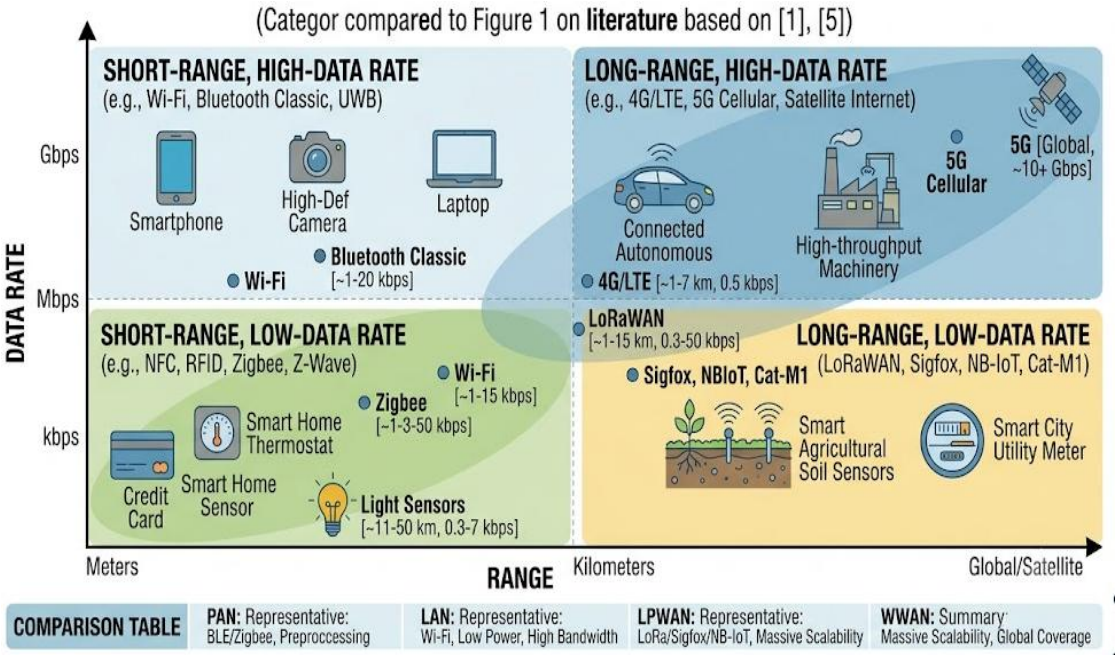


Figure 2: IoT wireless technologies by range and data rate

Application Domains

The principal application domains of the Internet of Things are represented in Figure 3, showing the smart home, smart city, industrial systems, healthcare, agriculture, and transportation as domains served by the sensing, communication, and processing of the Internet of Things. This representation conveys the breadth of application of the field [8], [9].

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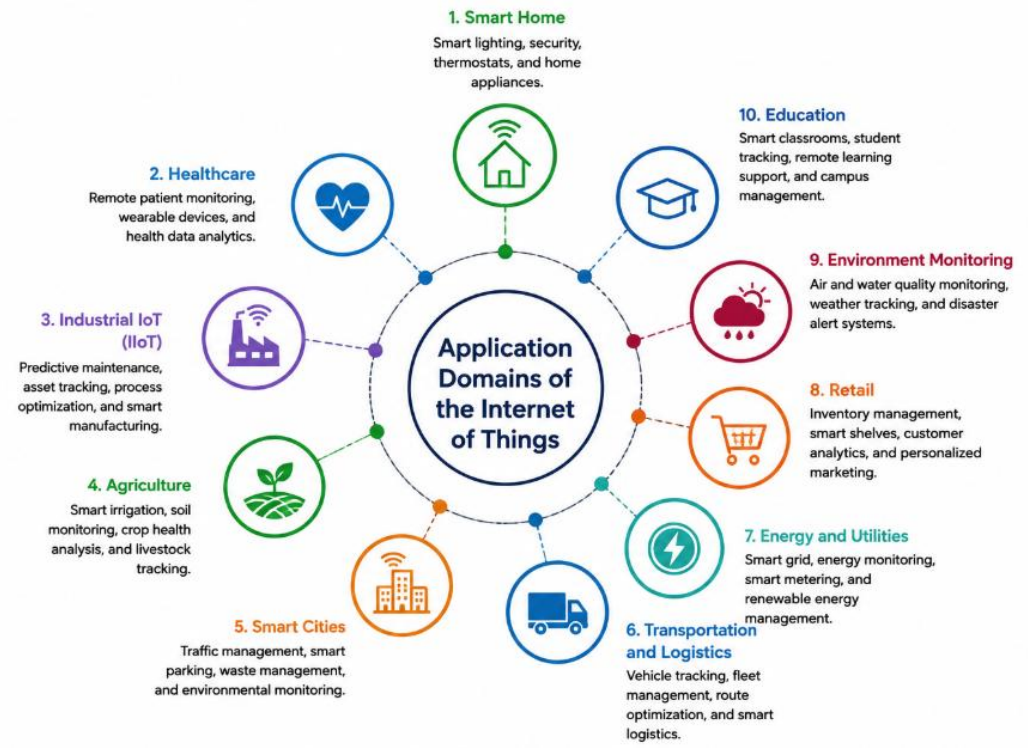


Figure 3: Application domains of the Internet of Things.

RESULTS AND FINDINGS

Architecture

Table 1 sets out the layers of the architecture and their functions, and Figure 1 depicts the architecture. The findings show that the system is organised into a perception layer that senses and acts, a network layer that provides connectivity, an edge layer that processes data near the source, and an application layer that provides services, and that the layers interact through the flow of data and control.

Table 1: Layers of an IoT architecture.

Layer	Function	Elements
Perception / sensing	Sense and act on the world	Sensors, actuators, RFID
Network / communication	Connectivity and transport	Radios and messaging protocols
Edge / fog	Local processing	Gateways, edge nodes, TinyML
Application / cloud	Analytics and services	Storage, dashboards, logic

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The finding is that this layered architecture provides a clear separation of concerns, allowing the components of a system to be designed and combined systematically, and accommodating the placement of processing at the edge or in the cloud according to the needs of the application for latency, bandwidth, and privacy [1], [3].

Communication

Table 2 sets out the communication technologies and Table 3 the messaging protocols, and Figure 2 depicts the technologies. The findings show that the radio and network technologies range from short-range technologies for the home and personal area to wide-area low-power and cellular technologies, chosen by range, power, and data rate, and that the messaging protocols, distinct from the radios, range from lightweight publish-subscribe and constrained protocols for constrained devices to heavier protocols for integration. The finding is that communication involves two separate choices, the radio and the messaging protocol, and that each is made to suit the constraints of the device and the network and the requirements of the application, so that a single system may combine several technologies and protocols across its layers [5], [6], [7].

Table 2: IoT connectivity technologies (representative).

Class	Technologies	Characteristic
Short-range	BLE, Zigbee, Wi-Fi, Thread	Home / personal area
Mesh & interoperability	Thread, Matter, Zigbee 3.0	Smart-home interoperability
Low-power wide-area	LoRaWAN, NB-IoT, LTE-M	Long range, low power
Cellular	4G / 5G	High rate, low latency

Table 3: IoT messaging protocols (representative).

Protocol	Description
MQTT	Lightweight publish-subscribe; dominant for telemetry
CoAP	Constrained, REST-like protocol over UDP
AMQP	Reliable messaging for enterprise integration
HTTP / REST	Widely compatible; heavier for constrained devices

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Applications and Challenges

Figure 3 depicts the application domains, and the findings survey them and the challenges. The findings show that the Internet of Things is applied across the smart home, the smart city, industrial systems, healthcare, agriculture, and transportation, using its sensing, communication, and processing to monitor and automate, and that it faces challenges of device constraints, security and privacy, interoperability, and scale. The finding is that the breadth of application reflects the generality of the architecture, which connects sensing and action to analytics and services, while the challenges reflect the difficulty of doing so securely and interoperably at scale with constrained devices, so that these challenges are central concerns of the field and the subject of continuing work [8], [9], [10].

DISCUSSION

The principal point of this review is that the Internet of Things provides a flexible, layered architecture for connecting the physical and digital worlds, and that its communication protocols and its processing are chosen to suit the constraints of devices and networks and the requirements of applications. The layered architecture separates sensing, communication, processing, and services, allowing systems to be built from heterogeneous components in a structured way; and the placement of processing at the edge or in the cloud allows the system to balance latency, bandwidth, and privacy. This flexibility is the reason the Internet of Things has been applied so widely [1], [3].

The communication of the Internet of Things illustrates the matching of technology to constraint. The separation of the radio, which carries the bits, from the messaging protocol, which structures the data, allows each to be chosen independently: a short-range technology for a home device or a low-power wide-area technology for a remote sensor, and a lightweight publish-subscribe protocol for telemetry or a constrained protocol for a very limited device. The dominance of lightweight protocols for constrained devices reflects the central constraint of the field that many devices have very limited power, memory, and processing, and that communication must be efficient. The choice of technology and protocol is therefore a central part of the design of a system [5], [6], [7].

The challenges of the Internet of Things are as important as its capabilities. The security and privacy of systems with many, often weak and physically accessible, devices are difficult to

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ensure, and the large attack surface is a serious concern; the interoperability of heterogeneous devices and standards is a persistent difficulty, which recent interoperability standards seek to address; and the scale of systems with vast numbers of devices strains management and networks. These challenges are the subject of continuing research and standardisation, and their resolution is essential to the safe and effective growth of the field. Presented together, the layered architecture, the communication technologies, and the application domains convey the Internet of Things as a connected whole. Specific technologies and standards are representative of a rapidly evolving field, and certain figures are illustrative and convey structure rather than exact configurations.

LIMITATIONS

This study is a review of a rapidly evolving field and presents the architecture, technologies, and applications of the Internet of Things in summary form; the technologies and standards named are representative examples rather than an exhaustive or final account, and the field will continue to change. The review addresses the subject at a high level and does not provide detailed technical or security analysis or measured data. The architecture, technologies, and application domains shown in the figures are illustrative and schematic rather than exact configurations. Readers requiring authoritative and current detail are referred to the primary literature and to the relevant standards and specifications.

FUTURE SCOPE

Further study building on this account can proceed in several directions:

- Advancement of edge and fog computing and on-device machine learning for IoT.
- Development of secure and privacy-preserving IoT systems and device identity.
- Improvement of interoperability through standards such as Matter and Thread.
- Study of scalable architectures and management for very large deployments.
- Integration of the Internet of Things with fifth- and sixth-generation networks.
- Investigation of energy-efficient communication and long-lived devices.

Pursuing these directions would strengthen the security, interoperability, and scalability of the Internet of Things.

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CONCLUSION

This paper has reviewed the architecture, communication protocols, and applications of the Internet of Things. It describes the layered architecture, a perception layer that senses and acts, a network layer that connects, an edge layer that processes near the source, and an application layer that provides services; the communication technologies, from short-range to wide-area, and the messaging protocols, from lightweight publish-subscribe and constrained protocols to heavier ones, that structure the data; the processing of data at the edge, including machine learning on constrained devices; and the application domains, from the smart home and city to industry, healthcare, agriculture, and transportation. The central conclusion is that the Internet of Things provides a flexible architecture for connecting the physical and digital worlds, that its protocols are chosen to suit the constraints of devices and networks, and that it faces significant challenges of security, interoperability, and scale that are central to the field. Specific technologies and standards are representative of a rapidly evolving field, and certain figures presented are illustrative.

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