# Internet of Things

Subjects: Computer Science, Information Systems
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The Internet of Things (IoT) refers to a system of interrelated, internet-connected objects that are able to collect and transfer data over a wireless network without human intervention. The term IoT has been considered as an expanding technique applied in various applications and functions, from smart environments and houses to personal healthcare and others [1]. It is described as a smart concept for the internet relating everything to the Internet and data organization and information exchange [2]. The key features required for employing a large-scale IoT are low-cost sensors, highspeed and error-tolerant data communications, smart computations, and numerous applications.

Keywords: 6G ; spectrum management ; 5G ; Carrier Aggregation (CA) ; Cognitive Radio (CR) ; small cell ; high-spectrum access ; mmWave ; M-MIMO

## 1. Introduction

Large-scale IoT intelligent systems have become more efficient and effective by using the properties of “symmetry” and “asymmetry”. This can help in a range of IoT applications, for example, in water quality analytics, bee colony status monitoring, accurate agriculture, data communication balancing, smart traffic management, spatiotemporal predicting, and intelligent engineering. Several studies are currently working on IoT technologies to sustain their necessity in platforms developing technology [3]. Although there are diverse definitions and explanations for understanding IoT, it has a subsequent edge associated with the assimilation of the physical world with the virtual one of the internet [4].

The paradigm of IoT is simplified as any-time, any-place, and any-one connected [5]. The implementation of this technology makes things and people closer and everyday life easier [6]. The purpose of IoT is to ensure a connection between devices, where each provides information and data. These devices are generally personal objects that are frequently carried, including smartphones, vehicles, healthcare devices, and office connected devices [7]. Moreover, Radio-Frequency Identification (RFID) is considered to be one of the first applications that saw the light and has played a crucial role in numerous technologies, such as sensors, smart objects, and actuators [8]. However, Machine-to-Machine communication (M2M) [9] and Vehicle-to-Vehicle communication (V2V) [10] represent the actual applications showing the significant advantages of IoT [11][12].

## 2. IoT Applications

Figure 1 represents a complete taxonomy of IoT in the significant fields of application. The principal areas of application are focused on health care, the environment, smart cities, commercial, industrial, and infrastructural fields [13][14].

**Figure 1.** Taxonomy of IoT applications.

The applications and use of IoT in the different domains are what drive and explain the development of this new trend, leading to the acceptance of IoT by the new world [15]. The study of IoT applications improves the understanding and enhancement of IoT technology, and thus, the design of new systems for newly developed cases [16]. The concept of IoT can be summarized as generating daily information from an object and transferring it to another one. Therefore, enabling communication between objects makes the range of IoT applications extensive, variable, and unlimited [17][18] (Tables 1-6).

**Table 1.** IoT healthcare applications.

| Reference | Focus Area | Application | Protocol | Device |
|---|---|---|---|---|
| [19] | **Disease management system to improve reliability** | **A guide for IoT healthcare service providers** | **-** | **Independent hand-held device and smartphones** |
| [20] | **Healthcare monitoring for chronic diseases like depression and diabetes** | **Battery energy efficiency approach using a machine learning technique** | **-** | **Wearable devices** |
| [21] | **Healthcare monitoring system which uses low-cost sensors and ensures a lower energy consumption** | **New architecture and paradigm of monitoring** | **XMPP** | **Smartphone** |
| [22] | **Mobile medical home monitoring system to improve the rapidity of factor measurements and ensure a low energy consumption** | **A new paradigm for mobile medical home monitoring** | **-** | **Wearable device** |
| [23] | **Adaptive security management based on metrics to enhance security** | **Adaptive security management standard** | **-** | **Boy sensors** |
| [24] | **Synthesis method for e-health to ensure high availability** | **A new structure for e-health** | | **In connection with the patient's body** |
| [25] | **IEEE 802.15.4 transceiver with a low error rate and a higher probability** | **Framework** | **IEEE 802.15.4** | **Wearable device** |
| [26] | **An efficient protocol to counter PUEA attacks** | **Algorithm and structure protocol** | **Multi-tier device-based authentication protocol** | **-** |
| [27] | **Biotelemetry application to ensure lower costs and energy consumption** | | **-** | **Wearable antennas** |
| [28] | **Energy-efficient routing protocol to ensure a lower energy consumption** | **Implementation and algorithm** | **The path routing protocol in WSN** | **-** |
| [29] | **Super-resolution algorithm for healthcare images with slower response time and cost** | | **-** | **Multi-kernel SVR learning-based image super-resolution** |
| [30] | **Healthcare monitoring system with lower delay rate and time response** | **A new algorithm for healthcare monitoring system** | **NB-IoT** | **-** |
| [31] | **Human factor evaluation in information exchange in the healthcare environment** | **It promotes data exchange among healthcare staff and healthcare providers** | **-** | **EPR system in hospital emergency department** |
| [32] | **Healthcare managing system developed through MySignals following LoRa wireless network** | **Collecting human body data** | **LoRa** | **Biosensors attached to the body** |
| [33] | **Focusing on chronic conditions beyond the office visit** | **Iraqi health information system** | **-** | **Wearable sensors** |

**Table 2.** IoT environmental applications.

| Reference | Focus Area | Application | Protocol | Device |
|---|---|---|---|---|
| [34] | **Monitor and control many environmental factors of henhouses in chicken farms** | **Henhouse system** | **MAC Protocol** | **Smart devices** |
| [35] | **IoT ecological monitoring system** | **A prototype for wild vegetation environment monitoring** | **-** | **Wireless sensor network** |
| [36] | **The revival of a rural hydrological/water monitoring system** | **Link located in Tasik Chini** | **LoRaWAN TCP/IP** | **Cellular BS and PC** |
| [37] | **Design and modeling of a sensible home automation system** | **Smart home** | **RFID** | **Smart home system** |
| [38] | **A model for smart disaster management using ICT** | **Smart cities** | **-** | **-** |
| [39] | **Identify critical challenges in ozone mitigation** | **Department of Environment Malaysia** | **-** | **-** |
| [40] | **Development of a Greenhouse Gases monitoring system** | **Remote area** | **-** | **NetDuino 3 WIFI** |

**Table 3.** IoT smart city applications.

| Reference | Focus Area | Application | Protocol | Device |
|---|---|---|---|---|
| [41] | **Semantic-aware mobile crowd-sensing** | **Service composition in smart city** | **Cellular** | **Smartphone and laptop** |
| [42] | **Digital forensics** | • Smart cities<br>• Smart homes<br>• Wearables smart grids | | |
| [43] | **Location finding along with the updated location configuration features** | • Emergency informing<br>• Dog tracking<br>• Monitoring indoor conditions | **LoRa** | **Sensor device inside an 'umbrella tube'** |
| [44] | **Big Data processing** | **Smart home** | **Bluetooth low energy (BLE)** | **MapReduce** |
| [45] | **Analyze and predict the performance of applications used in scalable platforms** | **Smart home** | **LoRa** | **Remote device and server** |
| [46] | **Context-aware service composition** | **Smart home** | **wEASEL** | **Smartphone** |
| [47] | **Cloud computing service composition** | **Vehicular monitoring** | **OIDM2M** | |
| [48] | **QoS service composition** | **Smart home** | **Bayesian networks** | **Smart devices** |
| [49] | **Manage heterogeneous data streams** | **Weather systems** | **ITS** | |
| [50][51] | **Traffic management and dynamic resource caching management** | **Street parking system** | **CoAP** | **WSN Devices** |
| [52] | **Real-time low power routing protocol** | **Smart city** | **RPL** | |
| [53] | **Fog-based architecture to manage IoT applications** | | **3G/4G Cellular WiFi ZigBee** | |

**Table 4.** IoT commercial applications.

| Reference | Focus Area | Application | Protocol | Device |
|---|---|---|---|---|
| [54] | QoS-aware service composition | Ecosystem | SoA | Smart devices |
| [55] | Semantic-aware service composition | Smart homes<br>Smart devices | 6LoWPAN<br>CoAP | Smart objects |
| [56] | QoS-aware multi-objective service composition | Composite service<br>Optimization service | - | - |
| [57] | QoS-aware service composition | Optimization service | IP | - |
| [58] | QoS-aware multi-agent composition | Web services | XMPP | - |
| [59] | Service accuracy | IoT Mashup application | RTM and FM | IoT sensors |
| [60][61] | Finance data flow system | Financial and banking sector | NFC | - |
| [62] | Etherum BC | Smart grid | BC | - |

**Table 5.** IoT industrial applications.

| Reference | Focus Area | Application | Protocol | Device |
|---|---|---|---|---|
| [63] | QoS-aware scheduling for service-oriented IoT devices | Scheduling if IoT | WSN | Mobile devices |
| [64] | Automatic learning of energy profiles and enhancing platform strategy | IoT Fog application | - | - |
| [65] | Content-based cross-layer scheduling | Industrial plant | IEEE 802.15.4-2015<br>TSCH MAC | - |
| [66] | Nonbeacon-enabled personal area network | Industrial monitoring and automation | IEEE 802.15.4-2015 | - |
| [67] | Ultra-low-power robust cell | Electronics industry | - | TFET SRAM |
| [68] | Concept of prognostics and systems health management (PHM) | Medical industry | - | Smart object appliance |
| [69] | The idea of Industrial IoT (IIoT) focusing on Low-Power Wide-Area Networks (LPWANs) | The indoor industrial monitoring system | LoRaWAN SF 7<br>LoRaWAN Fair Mod.<br>IEEE 802.15.4 | Industrial sensors |
| [70] | Industrial Blockchain Tokenizer (IBT) technology | Industrial robot security | Ad-hoc Haye | Sensors |

**Table 6.** IoT infrastructural applications.

| Reference | Focus Area | Application | Protocol | Device |
|---|---|---|---|---|
| [71] | SDN allocation method and IoT/fog | Very low and predictable latency applications | Openflow | Smart devices |
| [72] | Energy-efficient resource management | • Industry 4.0<br>• Internet of energy<br>• Big data streaming<br>• Vehicular mobility<br>• Smart city | TCP/IP<br>5G | Smart devices |

| Reference | Focus Area | Application | Protocol | Device |
|---|---|---|---|---|
| [73] | **Resource-efficient edge computing** | • Flying ad hoc networks for precision agriculture<br>• E-health<br>• Smart homes | **Cellular** | **Intelligent IoT device** |
| [74] | **Compressed sensing based on reakness for IoT applications** | • IoT scenarios consisting of local WSN | **-** | **-** |
| [75] | **Energy-efficient saving rectifier circuits** | • Energy harvesting<br>• Biomedical applications | **Bluetooth/WLAN** | **-** |
| [76] | **Low complexity parity checking** | **Wireless sensor networks** | **-** | • Wearable devices<br>• Smart sensors<br>• Smartphones |
| [77] | **QoS-independent and dynamic management** | **M2M** | **Cellular 3G and 4G** | **PC and smartphone** |
| [78] | **Software update management** | **Pervasive IoT applications** | **CoAP** | **-** |
| [79] | **Hazard-oriented analysis and implementation** | **Hazard-centric IoT application** | **-** | **-** |
| [80] | **Mobile broadband resource allocation in Fog networks** | **Mobile broadband** | **Cellular** | **Smartphones** |
| [81] | **WSDN management system** | • Device management<br>• Network management | **IEEE.802.15.4 IEEE 802.11** | **-** |

## 3. IoT Challenges

Table 7 summarizes the research challenges and opportunities for IoT applications.

**Table 7.** IoT application challenges and opportunities.

| IoT Application | Challenges | Opportunities |
|---|---|---|
| **Healthcare applications** | · User's privacy and data leakage [82]<br>· Standardization challenges [83]<br>· Scalability [84]<br>· Availability [85] | · Intelligent systems [156]<br>· Wide consumer market demand<br>· IoT-based applications with higher intrinsic value, but longer expected payback on investment [84] |

| | | |
|---|---|---|
| **Environmental applications** | · Authentication and authorization [83]<br>· Manage interdependencies between objects [83]<br>· Cost and modularity [86]<br>· Different granularity levels [84] | · Intelligent systems [83]<br>· Energy sustainability [83] |
| **Smart city applications** | · Authentication and authorization architecture challenges [83]<br>· Technical challenges [83]<br>· Mobility challenges [87]<br>· Interoperability [88]<br>· Big data analytics [88] | · Safety [89]<br>· Mobility-as-a-service [89]<br>· Traffic management and parking [89]<br>· Smart grid [90] |
| **Commercial applications** | · Privacy and security challenges [83]<br>· Encryptions vs. efficiency [88]<br>· Cost efficiency [91]<br>· Weakness in implementation methods [91] | · Exponential business growth [82]<br>· Internetworking [82] |
| **Industrial applications** | · Authentication and authorization [82]<br>· Hardware challenges [83]<br>· Efficiency and product loss [82]<br>· SW/HW and data attacks [82]<br>· Lack of willingness to share information [83] | · Smart factories [82]<br>· Smart grids [82]<br>· Intelligent coal mine [83]<br>· Energy sustainability [83]<br>· Smart factories [83] |
| **Infrastructural applications** | · Standardization challenges [83]<br>· Trust management [91] | · Energy efficiency [92]<br>· Real-time performance [92] |

## 4. IoT and Next Generation Protocol

The IPv6 suite primary protocol is neighbor discovery protocol (NDP), and is considered a replacement for the address resolution protocol (ARP) function in IPv4 [93]. The IPv6 protocol considers an extremely auspicious protocol for complicated and dispersed network applications in the era of IoT and Industry 4.0. However, its industrial implementation is slowly increasing in smart manufacturing methods [94]. As the number of devices in the network grows, the received data becomes complex and complicated, which requires more efficient approaches to be collected, sorted, and processed to achieve higher QoS values [95]. This has led researchers and developers to focus on designing various smart network protocols with self-organizing, self-management, and self-configure features, which can able full 3GPP standards and establish an uninterrupted network [96].

Moreover, the IoT6, which is the research project of the future IoT, is progressing positively, yet the unification of IPv6 and IoT is struggling with some challenges. The aim is to exploit the potential of IPv6 and related standards to overcome current shortcomings and fragmentation of the IoT [97]. Currently, the prime issue is the need to integrate the IPv6 and corresponding protocol with IoT, which can help to offer various applications such as automation, smart homes, and smart cities. However, due to wish to design an efficient protocol, some of the significant issues, such as the integration, complexity, scalability, security, reliability, flexibility, and homogeneity, need to be investigated for more IoT applications.

## 5. Conclusions

Various challenges have been summarized: Such as data privacy and scalability for the healthcare applications, authorization and cost issues for environmental applications, mobility and architecture challenges for smart city applications, cost and implementation difficulties for commercial applications, hardware and production problems for industrial applications, and standardization and trust issues for infrastructural applications. It has stated that various IoT applications still need to be exploited, such as blockchain technology, in order to maintain transaction information, enhance the existing structure performance, or develop next-generation systems. This can help to achieve extra safety, automatic business management, distributed platforms, offline-to-online information authentication, and so on. Moreover, the security and privacy characteristics of IoT are the key factors that can lead to its ability to be developed into a universally implemented technology in the future. However, the self-organizing and accessible nature of IoT makes it susceptible to numerous insider and outsider attackers. This may compromise the users' security and privacy, enabling access to a user's private data, financial damage, and eavesdropping. Therefore, more advanced optimized algorithms and protocols are required to secure data privacy. It can be concluded that by designing an energy- and cost-efficient intelligent network with potential business growth for IoT systems, the next generation of development technology can be produced.

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