

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.

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].

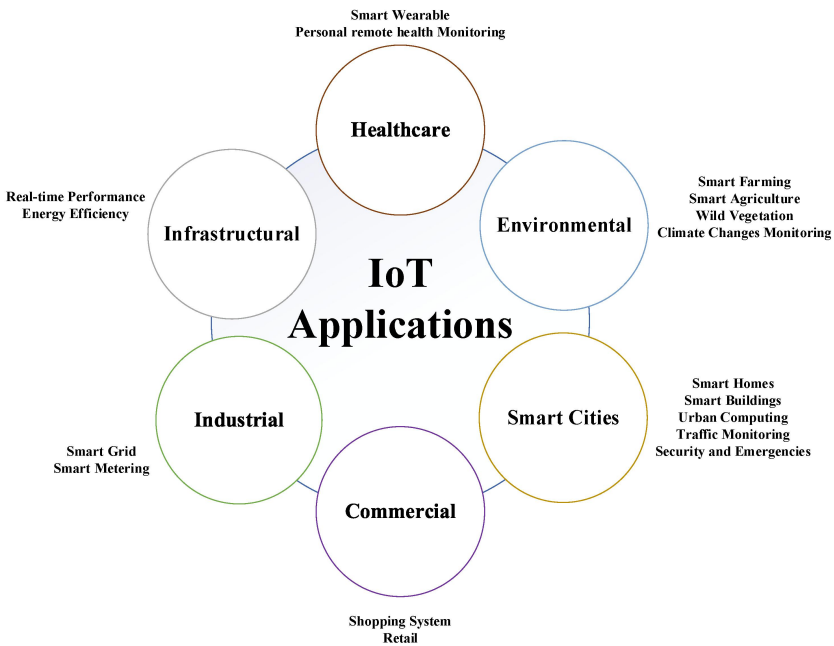


Figure 1. Taxonomy of IoT applications.

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

Reference	Focus Area	Application	Protocol	Device
[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	-	Body 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	Implementation and algorithm	-	Wearable antennas
[28]	Energy-efficient routing protocol to ensure a lower energy consumption		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

Reference	Focus Area	Application	Protocol	Device
[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	<ul style="list-style-type: none"> Smart cities Smart homes Wearables smart grids 		

Reference	Focus Area	Application	Protocol	Device
[43]	Location finding along with the updated location configuration features	<ul style="list-style-type: none"> Emergency informing Dog tracking 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 Smart devices	6LoWPAN CoAP	Smart objects

Reference	Focus Area	Application	Protocol	Device
[56]	QoS-aware multi-objective service composition	Composite service 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 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 LoRaWAN Fair Mod. 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	<ul style="list-style-type: none"> • Industry 4.0 • Internet of energy 	TCP/IP 5G	Smart devices
		<ul style="list-style-type: none"> • Big data streaming • Vehicular mobility 		
		<ul style="list-style-type: none"> • Smart city 		
[73]	Resource-efficient edge computing	<ul style="list-style-type: none"> • Flying ad hoc networks for precision agriculture • E-health • Smart homes 	Cellular	Intelligent IoT device
[74]	Compressed sensing based on reactivity for IoT applications	<ul style="list-style-type: none"> • IoT scenarios consisting of local WSN 	-	-
[75]	Energy-efficient saving rectifier circuits	<ul style="list-style-type: none"> • Energy harvesting 	Bluetooth/WLAN	-
		<ul style="list-style-type: none"> • Biomedical applications 		
[76]	Low complexity parity checking	Wireless sensor networks	-	<ul style="list-style-type: none"> • Wearable devices • Smart sensors • Smartphones

Reference	Focus Area	Application	Protocol	Device
[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	<ul style="list-style-type: none"> • Device management • 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	<ul style="list-style-type: none"> • User's privacy and data leakage [82] • Standardization challenges [83] • Scalability [84] • Availability [85] 	<ul style="list-style-type: none"> • Intelligent systems [156] • Wide consumer market demand • IoT-based applications with higher intrinsic value, but longer expected payback on investment [84]
Environmental applications	<ul style="list-style-type: none"> • Authentication and authorization [83] 	<ul style="list-style-type: none"> • Intelligent systems [83]

	<ul style="list-style-type: none"> · Manage interdependencies between objects [83] · Cost and modularity [86] · Different granularity levels [84] 	<ul style="list-style-type: none"> · Energy sustainability [83]
Smart city applications	<ul style="list-style-type: none"> · Authentication and authorization architecture challenges [83] · Technical challenges [83] · Mobility challenges [87] · Interoperability [88] · Big data analytics [88] 	<ul style="list-style-type: none"> · Safety [89] · Mobility-as-a-service [89] · Traffic management and parking [89] · Smart grid [90]
Commercial applications	<ul style="list-style-type: none"> · Privacy and security challenges [83] · Encryptions vs. efficiency [88] · Cost efficiency [91] · Weakness in implementation methods [91] 	<ul style="list-style-type: none"> · Exponential business growth [82] · Internetworking [82]
Industrial applications	<ul style="list-style-type: none"> · Authentication and authorization [82] · Hardware challenges [83] · Efficiency and product loss [82] · SW/HW and data attacks [82] · Lack of willingness to share information [83] 	<ul style="list-style-type: none"> · Smart factories [82] · Smart grids [82] · Intelligent coal mine [83] · Energy sustainability [83] · Smart factories [83]

Infrastructural applications

- Standardization challenges [\[83\]](#)
- Energy efficiency [\[92\]](#)
- Trust management [\[91\]](#)
- 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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