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# IoT Architecture Proposal from a Survey of Pedestrian-Oriented Applications

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**Abstract.** The significant improvement in the field of Internet of Things (IoT) has made human life more sophisticated. In fact, the IoT is covering devices and appliances that support one or more common ecosystems, and can be controlled via devices associated with that ecosystem. This control is only possible by building an architecture. Whether in indoor or outdoor environments, IoT services are only available to individuals or pedestrians because a IoT architecture enables that the quality of its components (i.e. Cloud/Fog servers, protocol communication and IoT devices) and the way they interact are directly correlated in terms of effectiveness and applicability. This paper aims to provide a comprehensive overview of an architecture in pedestrian-oriented applications in an IoT environment. Moreover, our survey has taken into account the main challenges and limitations of each component of IoT technology.

**Keywords.** Pedestrian-oriented applications, Cloud Computing, IoT Architecture, Open-source IoT platform

## 1. Introduction

The underlying principle of the Internet of Things (IoT) is collaboration, which offers a convenient way to bring together players from private and public sectors, creating new business models and projects. The widespread adoption of smartphones and other mobile devices plays into this as well since so many people now carry or wear devices that support interactions with IoT-driven services. In fact, it represents a comprehensive environment that interconnects a large number of heterogeneous physical objects or things to the Internet and is supported for an high level architecture like Cloud-centric Internet of Things (CIoT), Hub-Centric or Smartphone-Centric with a range of electronic components (i.e, sensors, smartphones, etc) in order to enhance the efficiency of services such as smart human mobility services and other real-time ubiquitous computing applications.

Besides, recent developments in wireless technology have made communication more familiar and reachable to everyone. Along with this, Bluetooth technology and interconnected devices have changed the role of Bluetooth. *"The world is just starting to see now, Bluetooth is everywhere. All these things are being brought into the connected world, and it's all using this Bluetooth Smart."*, Suke Jawanda, a spokesman for the Blue-

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tooth Special Interest Group. Both technologies are an action response to the growth of the IoT, improving spectrum efficiency, reducing latency, better mobility support and high connection density.

Independently of the type of connection (via Wireless or Bluetooth) we have the possibility to connect to the Internet or another device. And devices are increasingly relying on edge computing, or compute resources that are geographically closer to devices than traditional cloud resources [1]. Moreover, new applications require real-time computing power, and continue to drive edge computing systems. For instance, a Fog Computing (FC) architecture can represent an alternative to the centralized cloud service called Cloud Computing (CC), given that the connection is not guaranteed, and the continuously increasing number of connected devices represents a challenge for the connection bandwidth. Maybe an approach with multiple layers between the connected device and cloud services would be more appropriated.

Although there are several studies about components of IoT and smart cities, and the application fields of IoT-based solutions are plentiful, the convergence of these two areas needs further academic efforts for the thriving of IoT-based smart cities. For this reason, we are proposing an architecture which displays a set of components mentioned above. It brings together ubiquitous computing with sensors, and other devices such as smartphones, as well as, enabling the ability to connect any device and integrate a cloud with a range of online services in indoor or outdoor environments. The main driver of the communication combines Bluetooth Low Energy (BLE), Wireless Sensor Network (WSN), as well as protocol communications like Messaging Queue, Http or Socket without forgetting a Human Machine Interface (HMI). Therefore, it is beneficial to propose an IoT architecture that is appropriate and smart to handle individual or pedestrian contexts.

This paper is organized as follows. Section 2 addresses related work regarding a generic approach about components of IoT systems and where they can provide services to pedestrians or individuals. Section 3 focuses on the architecture of the IoT system proposed in this paper and a description of its main components. Finally, Section 4 presents the conclusion and future work.

## 2. Related Work

A typical IoT solution is characterized by many devices (i.e. things) that may use some form of gateway to communicate through a network to an enterprise back-end server that is running an IoT platform that helps integrate the IoT information. This is only relevant if we apply it in real-life contexts. Therefore, we relate some contexts where the elements of IoT help pedestrians in their day-to-day life.

### *2.1. Components of IoT*

There are different ways to connect each IoT component providing specific features and functionality required by any robust IoT solution. One of the most promising architectures aims to connect a smart device, for instance, a sensor module using Raspberry Pi for monitoring and controlling the parameters of an industrial plant and energy management directly to the Wi-Fi network without needing any additional hub to work. Beyond the help of CC which is used to store data, in this cloud centric architecture there is no need to install additional devices and it can be controlled from the smartphone [2]. Furthermore, the setup process is quite easy and straightforward for the user, but it relies on a connection to the Internet. Another alternative should be used. For instance, the *My Smart BT* project focuses on Android operating system-based Bluetooth Serial Port Profile (SPP) application [3], a smart device that is connected directly to a smartphone via Bluetooth and depends on the proximity of the other device. For real-time data transmissions between the connected devices they should be connected via Wireless internet. However, this architecture does not promote the data storage in a cloud computing platform. In turn, once many smart features could be set up without having a dedicated cloud infrastructure, in an hub-centric architecture a device cloud is also optional. For example, the *SensorHUB* framework provides a unified tool chain for IoT related application and service development [4]. SensorHUB is both a method and an environment to support IoT related application and service development; furthermore, it is an intermediary for connecting a smart device to another device and to the internet, since it usually connects to the Wi-Fi or Ethernet network.

The use of smartphones with control systems and the newest Mobile Network technology (5G), Wireless Fidelity (Wi-Fi) based on the IEEE 802.11 to Bluetooth 5.0 and standard-based low-power wide-area network (LPWAN) protocols are expected to take a big leap in terms of maturity and adoption in coming years [5]. However, if each of them work in an isolated way there are some limitations. First, although Mobile Network infrastructures have improved, enabling numerous devices requires extremely high performance interconnections under strenuous scenarios such as diverse mobility, extreme density, and dynamic environment but this is challenged by latency for some applications, expense and saturation in areas with high user density, whereas terrestrial mobile achieves the connectivity to indoor and ground-mobile users but is economically challenged when user density is sparse or intermittent [6]. The alternative, Wi-Fi, used for file transfers among most of the IoT devices and which includes any type of WLAN product support any of the IEEE 802.11 only serves as a means to enable indoor navigation, namely inside buildings, requiring a WiFi infrastructure. In turn, Bluetooth high-speed technology devices can deliver up to 24 Mbps of data, which is faster than the 802.11 WiFi standard, but slower than wireless-a or wireless-g standards, it is restricted to an indoor positioning area [7].

Because of the convergence of advanced infrastructures, driven by various devices in real-time communication, processing and storing are highly preferred for big data systems. Being part of a layered hierarchical architecture, computation and storage capabilities are distributed over a number of IoT devices that are located in proximity to the device layer. However, due to the location of the underlying IoT devices, which is very distant, the centralized cloud service is not suitable to perform real-time tasks, and some services can not tolerate the possible latency originating from this issue [8]. In other words, the explosive growth of internet-connected devices along with new applications that require real-time computing power continues to drive edge computing systems. Therefore, a decentralized cloud service could be a solution. Fog Computing (FC), first introduced by Cisco, resides in multiple layers between the device and Cloud service. It also represents an extension of traditional cloud-only models and not an alternative [2]. FC highlights the applications and services that include Commuted Vehicle, Smart Grid, Agriculture, Healthcare, Smart Cities, and, in general, Wireless Sensors and Actuator Networks (WSANs) [7] . Fig. 1 shows the conceptual architecture for fog computing, which works as an intermediate layer between the cloud and the users to provide real-time communications.

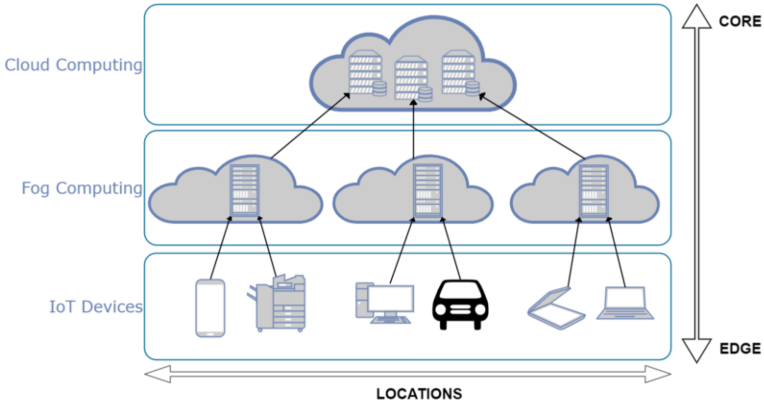


**Figure 1.** Fog/Cloud computing architecture between edge and core (adapted from [9]).

In this paper, it has been discussed how data is stored. In fact, data storage can be done locally on devices or in cloud storages. In the case of the cloud, to take better advantage of its architecture, some services have been developed such as Firebase, Google Cloud Plataform (GCP), Deployd, Microsoft Azure or Amazon Web Services (AWS). But, for the purpose of this study, it should run in realtime from Android, iOS and Web applications, include flexible rules to define the data structured, security, handle big data charges and server-side processing and enable NoSQL Database. Moreover, it should provide a service that can authenticate users using only client-side code (decentralized authentication service), ability to deliver messages (MQTT, websockets) supporting protocols to different platforms, as well as bring Machine Learning and strategic features (e.g, event driven or streams) features to applications [10]. Therefore, all these microservice applications should be associated to a complex infrastructure - FaaS (Function-as-a-Service) - that enables code execution in response to events.

The use of Internet of Things (IoT) in this type of cloud-computing service can be presented in multiple case studies. For example, [11] covers how to build IoT applications using arduino sensors and the power of Cloud. Focused on the various issues associated with the idea of Smart City, members of the ALGORITMI Center, Department of Informatics, University of Minho have developed the *SafeCity* project. It offers, among others, traffic flow forecasts; smart notifications (via MQTT); a city map based on the quantification of positive and negative feelings of its citizens and gamification engine to support and promote user engagement. This mobile application is specially focused on data collection and on fulfilling the entire Machine Learning pipeline. In [12] a comparison framework illustrates some factors to compare Fog and Cloud computing data transmission from the edge to the core level of the IoT environment and estimate the dataset with two factors: latency and accuracy analysis.

In summary, features discussed and justified in the given use cases include latency, hardware compatibility, data management and integration of different types of components (i.e. sensors, smartphones, computers and servers). For our study, these components provide more benefits using a decentralized architecture, because each of them is responsible for one of the activities (e.g. monitoring, analysis or collection of data) of the system, performing its functionality locally, but coordinated with peers. Therefore, once the features of an IoT application are known we will propose a new architecture.

### 2.2. Pedestrian Sensing

The proliferation of technological innovations has led to cities becoming ”smart”, hence the term ”smart cities”. And this idea is emerging day by day, once there is an intelligent and sustainable infrastructure in cities that is integrated with advanced technological solutions [13]. Besides 66% of the world population is expected to live in urban areas by 2050 [14]. Thus, it has become an important issue to keep track of footpath traffic and environmental parameters for urban planning, retail development, major event crowd assessments, pedestrian safety, traffic flow management and assessments of street development.

There are projects focused in people counting in high streets and city centres. They provide both real-time and historical data for big data analytics. Business-people looking to open a new shop or restaurant could be given accurate figures for footfall past their proposed location to help them assess the potential for their new venture. Other projects focused in occupancy counting inside public buildings and shopping centres were also implemented via thermal cameras, sensors and Wi-Fi [15] probe requests [16].

Smart Counters are attached to lampposts around the city. They have a wide range of applications in the surveillance of potential areas for the detection of unusual events, tracking customers in retail stores to control and monitor the movements of assets, monitoring elderly and sick people staying at home alone, to recognize and track people [17]. Furthermore, the process of counting people is complicated and very costly in terms of computing and money [18]. For example, in video camera technique, the number of people are determined on the image processing algorithm, allowing an accuracy rate of up to 95% for an indoor surveillance environment and 85% for outdoor applications [19]. Another popular method for human detection is thermal cameras. It is used for vehicle detection, spot smoldering fires inside a wall and detecting overheating electrical wiring. It retrieves information about temperature differences, detecting the infrared energy emitted by an object.

In turn, sensing technology is also used for the identification of objects and people. Among several applications, some potential applications are occupancy counting in smart buildings, bus and railway stations, smart parking systems and the amount of traffic at any given time and counting bicycles [20,21]. A pedestrian crossing is a part of the road painting and is designated for pedestrians to cross a road. Crosswalks are also usually situated where a considerable number of pedestrians is trying to cross a road, for instance near shopping areas, or where exposed road users (such as school children) frequently cross [22]. All this information projects open opportunities for cities to also provide the information directly to the public. Having this sort of information lets people avoid the busiest areas and help reduce any issues on the road, railway stations and helps monitor and support the promotion of healthy travelling and gives a measure of how green or pollution-free areas are within a city centre, or to monitor the effectiveness of sports activity, events and jogging routes within parks where specific rules are needed for the use of pedestrian crossings to ensure safety for example.

These human counting and tracking projects are conducted via broadcasted signals from devices such as smartphones, laptops and tablets. Although the usage of mobile communication covers a more extended range compared to Wi-Fi or ZigBee [23]. However, both build huge collect data infrastructure, enabling, for instance, an adequate understanding of the ongoing trends of pedestrian activity, helping in planning and responding to emergencies, and the city planner in making decisions quickly or being able to differentiate the peak and off-peak hours of individual zones and track zone-level occupancy tracking [24]. In addition, the data collected is transferred to the server and uploaded on the website for the public, but after some time, we will have enough IoT big data to help quantify the use of footpaths and cycle ways. This creates a city that uses technology to meet the complex needs of pedestrians.

## 3. IoT Architecture Proposal

In subsection 3.1, we discuss the differences between our IoT architecture and other IoT solutions. During the comparison the component's functionality are the key areas that are compared with other IoT architecture proposals. In the following subsection (3.2), the main components of the proposed IoT system are subdivided into four levels: Sensing layer, Network Layer - mainly describes the type of connects between a circuit of Iot devices which is also connected to the Internet - Data Processing Layer, although at a high level, approaches an online server/database architecture and, finally, Application layer.

### *3.1. Comparison of IoT Platforms*

Reflecting each parameter described in Table 1, our IoT architecture matches or adds components that already exist or are considered an innovation within others proposed platforms. From a summarized overview of the comparison, for example, although mentioned within the documentation, IoT Device component is not represented within the architecture of the IBM Watson IoT Platform [25]. Besides, the platforms Sitewhere, Amazon WebService IoT, and the Microsoft Azure IoT Hub further distinguish the concept of "Intelligent" Devices, which have already some kind of logical functionality included. In our architecture that kind of Devices are covered by IoT Device and IoT Middleware components.

**Table 1.** Comparison of various IoT platforms (adapted from [26]).

| | *Microsoft Azure* | *Amazon Web Services* | *IBM Watson IoT* | *Things.io* | *SiteWhere* |
|---|---|---|---|---|---|
| **Protocols** | HTTP, AMQP and MQTT | HTTP, MQTT and WebSockets | HTTP and MQTT | HTTP, MQTT, CoAP and WebSockets | HTTP, AMQP and MQTT |
| **Hardware** | Intel, Raspberry Pi2, Freescale and Texas Instruments | Broadcom, Marvell, Renesas, Texas Instruments, Microship and Intel | ARM, Texas Instruments, Raspberry Pi and Arduino Uno | Hardware agnostic | Hardware agnostic |
| **SDK Language** | .Net and UWP, Java, C and NodeJS | Java, C and NodeJS | C#, C, Python, Java and NodeJS | Python, NodeJS, MQTT, NodeJS HTTP, NodeJSCoAP and Joiled Node | Java, Vue, JavaScript, TypeScript and Smarty |
| **$3^{rd}$ party Integration** | REST API | REST API | REST API | REST API | REST API |
| **Dashboard** | Yes | Yes | Yes | Yes | Yes |

Obviously, each platform represents the core functionality, i.e., our IoT Middleware within the architecture. The differences lie in the granularity and the number of the components which make up the functionality of the IoT Middleware. Furthermore each platform enables the connection of further Applications. However, we also propose to split the location of big data storage in two ways: Fog Computing (FC) or Cloud Computing (CC). This mean that in the context of pedestrian-oriented application development user can access and share information in anyway and anywhere.

### 3.2. Components of the IoT architecture

This section explains the IoT architecture proposal in detail which maps the descriptions with different architecture areas. We start by defining all components shown in Fig. 2 starting from the top. To clearly distinguish between the concepts presented in this work and similar or equal related architectures mentioned in previous section, we highlight the elements of the reference IoT architecture presented in this work using italics.

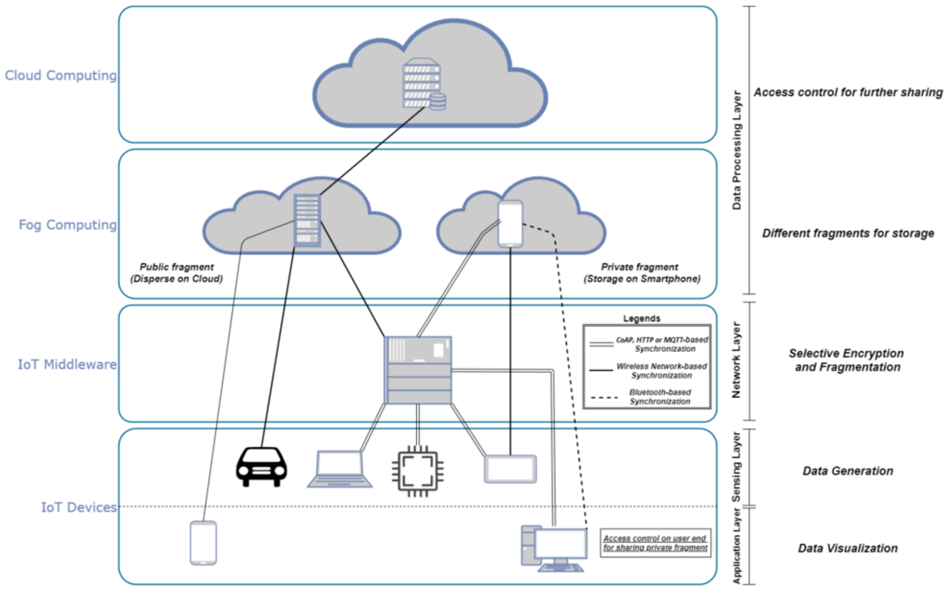


**Figure 2.** Architecture proposal for pedestrian-oriented applications.

#### 3.2.1. Sensing Layer

In this layer we can include the Data from *IoT Devices* and Commands to *IoT Devices* components of our reference architecture. Devices are either (i) self-contained or (ii) connected to another, bigger system. The *IoT Middleware* represents such a system. Furthermore, they also represent our Sensor and Actuator components. In crowd sensing, the arduino is one the most interesting boards in the sensor family. It is easily connected to a computer and uses the Arduino IDE. It has a built-in antenna and its format is ideal for prototyping environments, fitting easily into a protoboard. Moreover, it integrates a set of sensors like temperature or motion sensors and is used for the collection of data from an object of measurement. Also, the IoT mobile device in this case study can be based on smartphones, smartwatches or other devices where Wireless and Bluetooth connectivity is used for synchronizing mobile devices and transferring data.

### *3.2.2. Network Layer*

We propose an action-based framework that acts as middleware (or controller) between the user and smart appliances and which allow the user to control these heterogeneous devices in a federated manner. This middleware maintains the integrity of an instruction sent to the device and employs the mechanism so that only authenticated users can access them. Additionally, it is the central entity of our proposed framework, running on a machine in the vicinity of a FC and CC smart network. We also incorporate Android, IOS or Web applications which receive input from the Human System Interaction (HSI) in smart home appliances.

Although they are not explicitly depicted within the architecture, devices can communicate with the platform via different protocols (i.e. CoAP, MQTT, and HTTP). Based on this, we propose our architecture and the mapping of the open-source IoT platform SiteWhere onto our reference architecture. In this type of IoT platform the concept of a Gateway is present between the devices and the platform [27], but not pictured as a separate component. The main functionality of the platform is provided by the Device Management and the Communication Engine. Consequently, those components are considered the *IoT Middleware* of our reference architecture. The REST APIs and Integration component enables the connection of further Applications to the platform.

### *3.2.3. Data Processing Layer*

Assuming all smart devices and smartphones can communicate using different protocols like HTTP protocol, socket or MQTT via Bluetooth or Wireless with this controller, or directly between another smart device (private fragments), other devices can be connected directly with controllers located from outside the home network (public fragment). They offer a service on the fog platform to cater for the need of powerful computation and big data storage capabilities from the form of REST API service. Therefore, this service has a major role to transfer data from edge device (IoT Device) to Fog node and from Fog node to Cloud (Internet).

Increasing device density generates a lot of data and poses new challenges for the IoT infrastructure. For data transmission in a *Fog server*, a smartphone or server is needed. These devices access the user's storage as Fog storage via API . Other features are supported, such as encryption, authentication, and cloud data storage, it is ideal for access control, storage and efficient sharing in real-time. Another advantage is it uses the HTTPS communication protocol that supports bidirectional communication encryption between a client and server. Therefore, in our architecture we will use Software as a Service (SaaS) to relieve this pressure of Big Data Storage, beyond allowing users to connect to the applications through the Internet on a subscription basis, a private fragment for storage on smartphone and a public fragment to disperse on Cloud as privacy policy, using a NoSql Database mainly as a Big Data Sharing centre.

### *3.2.4. Application Layer*

The Application component represents software which uses the *IoT Middleware* to gain insight into the physical environment, manipulate the physical world and is responsible for delivery of various applications to different users in IoT. It also implements and presents the results of the data processing layer to accomplish different applications of IoT devices. Moreover, it does so by requesting Sensor data or by controlling physical actions using Actuators. The role of this layer is to use the data collected from temperature sensor, flow meter and Global Positioning System (GPS) positions, and other data sources that was sent to the Cloud service. And finally, the application user interface receives this information, and must take the required decisions and can also request additional information from the application.

## 4. Conclusion and Future Work

A more reliable Internet of Things (IoT) architecture is proposed in this paper. The proposed improved layered architecture of IoT is made up of four layers, and there is a sort of function distribution on each layer. It involves an entire ecosystem of tools and services that come together to deliver a complete solution. Knowing its key components and how to integrate them to guarantee a robust and optimized architecture will be a challenge. Regardless of the use case, it should involve at least devices, connectivity, gateways and edged compute. While IoT devices make up the physical hardware component of our solution, connectivity is fundamental for them to send state data and receive commands from our decentralized platform.

Moreover, there are a set of options for how device-to-platform connection is made and it depends on the environment and constraints of the device. This is, if the device is outside and moving around we use cellular connectivity. In indoor environments, Ethernet or Wi-Fi connectivity is a better option. For battery-powered devices lower energy options must be used like Bluetooth or LPWAN. And finally, in gateways and edge compute, in some cases the devices can't connect directly to the central cloud platform or or other platforms in intermediate layers and instead require the use of an IoT gateway to bridge the gap between local environment and platform. This gateway is required when using Wireless technologies like Bluetooth and LPWAN, since those don't provide any direct connection to the network or the Cloud. Therefore, due to its reliability and feasibility the proposed layered architecture is useful to many kinds of applications. In future work, there will be a focus on building new model applications based on this proposed IoT architecture.

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