Review

# An overview of the Internet of Things for people with disabilities

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A R T I C L E   I N F O

A B S T R A C T

Currently, over a billion people including children (or about 15% of the world's population) are estimated to be living with disability. The lack of support services can make handicapped people overly dependent on their families, which prevents them from being economically active and socially included. The Internet of Things can offer people with disabilities the assistance and support they need to achieve a good quality of life and allows them to participate in the social and economic life. In this paper, an overview of the Internet of Things for people with disabilities is provided. For this purpose, the proposed architecture of the Internet of Things is introduced. Different application scenarios are considered in order to illustrate the interaction of the components of the Internet of Things. Critical challenges have been identified and addressed.

## Contents

## 1. Introduction

The Internet of Things (IoT) is a technological revolution in computing and communications. It depicts a world of networked smart devices, where everything is interconnected (ITU Internet Reports, 2005) and has a digital entity (Pascual et al., 2011). Everyday objects transform into smart objects able to sense, interpret and react to the environment thanks to the combination of the Internet and emerging technologies such as Radio-frequency Identification (RFID) (Amaral et al., 2011), real-time localization and embedded sensors.

This technological evolution enables new ways of communication between people and things and between things themselves (Tan and Wang, 2010). In this paper, an overview of the IoT for people with disabilities is provided. The first ever World report on disability has been published in June 2011 (World Health Organization (WHO), 2011). Based on the 2010 population estimate (6.9 billion) and the 2004 disability prevalence estimate (World Health Survey and Global Burden of Disease), over a billion people including children (or about

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15% of the world's population) are estimated to be living with disability (World Health Organization (WHO), 2011). The report (World Health Organization (WHO), 2011) also revealed that 110 million people have very significant difficulties in functioning, while 190 million have "severe disability"—the equivalent of disability inferred for conditions such as quadriplegia, severe depression or blindness.

In addition, a recent study from the Organization for Economic Co-operation and Development (OCED) (2010) showed a huge labor market disadvantage. On average, the employment rate was 44% and 75% for people with and without disabilities, respectively. The inactivity rate was 49% and 20% for people with and without disabilities, respectively. Therefore, the inactivity rate for disabled people is about 2.5 times higher. Furthermore, the lack of support services such as building access, transportation, information and communication can make handicapped people overly dependent on their families, which prevents them from being economically active and socially included.

We strongly believe that the Internet of Things can offer people with disabilities the assistance and support they need to achieve a good quality of life and allows them to participate in the social and economic life. Assistive IoT technologies are powerful tools to increase independence and improve participation. Therefore, the purpose of this paper is to analyze how people with visual, hearing and physical impairments can interact with and benefit from the IoT. To the best of our knowledge, this is the first paper that discusses the IoT for handicapped people.

The paper is structured as follows. In the Section 2 we discuss the proposed architecture from a technical perspective. In Section 3, its application scenarios are described. In Section 4, the benefits of, and main research challenges to the IoT for handicapped are outlined in Section 5. Finally, the paper is concluded in Section 6.

## 2. IoT architecture

The proposed IoT architecture from a technical perspective is shown in Fig. 1. It is divided into three layers. The basic layer and their functionalities are summarized as follows:

- *Perception layer*: its main function is to identify objects and gather information. It is formed mainly by sensors and actuators, monitoring stations (such as cell phone, tablet PC, smart phone, PDA, etc.), nano-nodes, RFID tags and readers/ writers.
- *Network layer*: it consists of a converged network made up of wired/wireless privately owned networks, Internet, network administration systems, etc. Its main function is to transmit information obtained from the perception layer.
- *Application layer*: it is a set of intelligent solutions that apply the IoT technology to satisfy the needs of the users.

Next, we describe in greater detail the components of each layer.

### 2.1. Perception layer

This layer provides context-aware information concerning the environment of disabled people. The components of this layer according to the disability of the person (visually impaired, hearing impaired or physically impaired) are described next.

### 2.1.1. Visually impaired

The components designed for the visually impaired are: (1) *body micro- and nano-sensors* and (2) *RFID-based assistive devices*. Next, those components are introduced.

*2.1.1.1. Body micro- and nano-sensors.* In Schwiebert et al. (2001), a *retinal prosthesis* is developed to restore some vision to patients affected by retinitis pigmentosa and age-related macular degeneration, two diseases that cause degenerative blindness. Although these disorders are characterized by the progressive loss of photoreceptor (rod and cone) cells of the outer retina, they do not affect the inner retinal ganglion nerve cells which form the optic nerve (Ye et al., 2010). Consequently, a camera mounted on a pair of glasses can be used to transmit image data to an implant attached to the retina, which is formed by an array of body micro-sensors. This artificial retina (Schwiebert et al., 2001) uses electrical impulses to stimulate the appropriate ganglion cells, which convert these electrical impulses into neurological signals. The generated response is carried via the optical nerve to the brain.

Currently, researchers are working to develop an *artificial retina at the nanoscale*. The venture Nano Retina is developing Bio-Retina, a bionic retina that incorporates several nano-sized components in a tiny retinal implant (see Fig. 2). Bio-Retina is designed to replace the damaged photoreceptor in the eye with the equivalent of a 5000 pixel (second generation) retinal implant. It transforms naturally received light into an electrical signal that stimulates the neurons, which send the images received by Bio-Retina
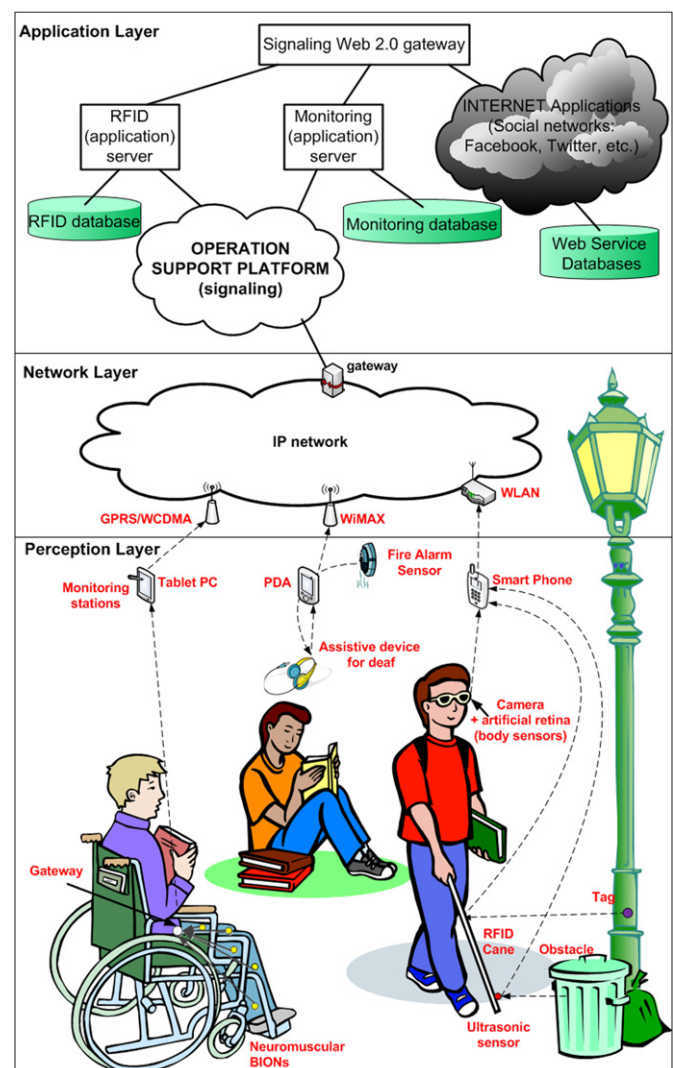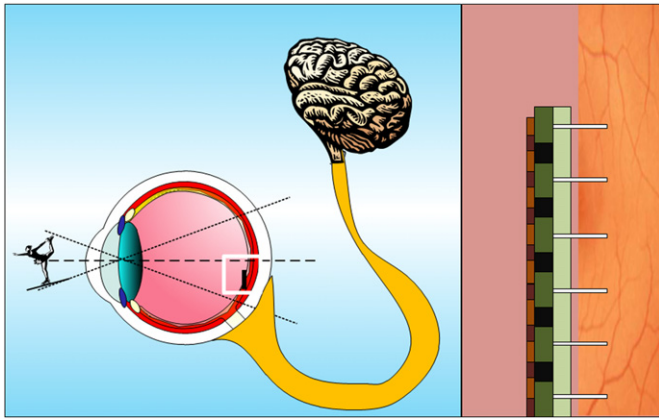


**Fig. 1.** Proposed architecture.

**Fig. 2.** Positioning of the retinal implant (left); bionic chip and its interface with the retina (right).

to the brain. The implant's nano-sized components are powered by a special pair of activation eyeglasses.

In the next years, as technology evolves, it will be possible to send information concerning the images captured by the artificial retina towards the monitoring station (smart phone) (see Fig. 1), so that new IoT applications to help people with visual impairments in their orientation, identification of faces, etc. will be developed.

*2.1.1.2. RFID-based assistive devices.* An essential RFID-based application is the *navigation system*. It helps blind people find their way in an unfamiliar area. RFID tags are distributed through the area. They can for example be placed in the center of the sidewalks to orient the blind person and prevent possible falls near the border of the sidewalk (Saaid et al., 2009).

The RFID cane (see Fig. 1) has a tag reader with an antenna that emits radio waves; the tags respond by sending back their stored data, hence identifying the location of the blind person. The tag reader (RFID cane) transmits via Bluetooth or ZigBee the data read from the RFID tag, which includes the tag ID string (D'Atri et al., 2007). This data is sent from the monitoring station through the network layer to the RFID server of the application layer. The blind person can record the destination's name as a voice message using the monitoring station. Directions are received by the monitoring station and played as voice messages (Shiizu et al., 2007).

An *obstacle detection system* based on an ultrasonic sensor can also be added (Martin et al., 2009). The sensor is mounted on the RFID cane to extend its effective range and perceive obstacles the cane alone would not be able to detect (such as a garbage can in Fig. 1). A voice message played at the monitoring station alerts the visually impaired when an obstacle is detected. A multiple sensor-based shoe-mounted sensor interface is also developed in Zhang et al. (2010) as a supplementary device to the cane to detect obstacles within 61 cm ahead of the visually impaired.

A widespread approach for outdoor navigation relies on Global Positioning System (GPS). It does not require tags to work. However, its resolution is limited (few meters) and it cannot work properly indoors. Therefore, some navigation systems for the visually impaired integrate both technologies (RFID and GPS) (Yelamarthi et al., 2010).

### 2.1.2. Hearing impaired

The components designed for the hearing impaired are: (1) *assistive devices and sensors* and (2) *RFID-based devices*. Next, those components are introduced.

*2.1.2.1. Assistive devices and sensors.* People who are hearing impaired can benefit from external or internal (implanted in the ear) assistive devices that improve hearing. Different types of sensors (such as doorbell or smoke detectors (see Fig. 1)) detect events or malfunctions that give rise to alarm conditions. Consequently, an alarm signal is sent from the sensors to the monitoring station, which forwards it to the assistive device as an amplified alarm signal. The deaf person can also be notified with visual (flashing light) or vibrotactile signals (vibration motor) (Ren et al., 2006).

On the other hand, HandTalk (Sarji, 2008) is a low-cost wireless glove designed to help the hearing impaired communicate with those who are not familiar with the American Sign Language (ASL). It recognizes basic ASL hand signs and converts them into voice by interfacing with a Java enabled monitoring station (cell phone or PDA). Basically, the glove is fitted with flex sensors (passive resistive devices that can be used to detect bending or flexing) along the fingers. The position (bending) of the fingers is sensed and sent to a monitoring station using Bluetooth. If the sensed data matches the set of values associated with an ASL sign of a cached database, the sign is converted into text and finally into speech.

*2.1.2.2. RFID-based devices.* RFID-tagged toys can be used to help deaf kids learn how to use sign language (see Section 3).

### 2.1.3. Physically impaired

The components designed for the physically impaired are: (1) *body sensors, actuators and neurochips* and (2) *body sensors and RFID technology*. Next, those components are introduced.

*2.1.3.1. Body sensors, actuators and neurochips.* Body sensors and actuators can be useful to perform functional reanimation of paralyzed limbs. Sensors attached to the nerves can detect the user's intention to move certain muscles and actuators can stimulate these muscles to restore the ability to move. A paralytic can be equipped with neuromuscular micro-implants named BIOnic Neurons (BIONs) (Tan and Loeb, 2007), which are modularly designed wireless capsules that can be injected at several sites in the body near motor nerves. Their main function is to reanimate paralyzed limbs. They receive power and digital command data from an external radio frequency coil and deliver stimulating current pulses to recruit the motor neurons and activate associated muscles. Sensors are required by the BION to detect voluntary command signals and to provide sensory feedback to regulate neuromuscular stimulation. This technology is used to create movements in limbs paralyzed by upper motor neuron disorders such as spinal cord injury and stroke. BIONs perform Functional Electrical Stimulation (FES), a technique that uses electrical currents to activate nerves innervating extremities affected by paralysis. This way, motor functions are recovered. Some examples of FES applications involve the use of neuroprostheses that allow people with paraplegia (Williamson and Andrews, 2000) to stand, walk, or restore hand grasp function in people with quadriplegia.

On the other hand, researchers at the Washington National Primate Research Center have deployed tiny, battery-powered implantable brain–computer interfaces (BCIs) (Fazel-Rezai, 2011) called neurochips in animals and are working on their implantation in humans.

When awake, the brain continuously governs the body's voluntary movements. This is largely done through the activity of nerve cells in the part of the brain called the motor cortex. These nerve cells, or neurons, send signals down to the spinal cord to control the contraction of certain muscles, like those in the arms and legs.

The neurochip records the activity of motor cortex cells. It can convert this activity into a stimulus that can be sent back to the brain, spinal cord, or muscle, and thereby set up an artificial
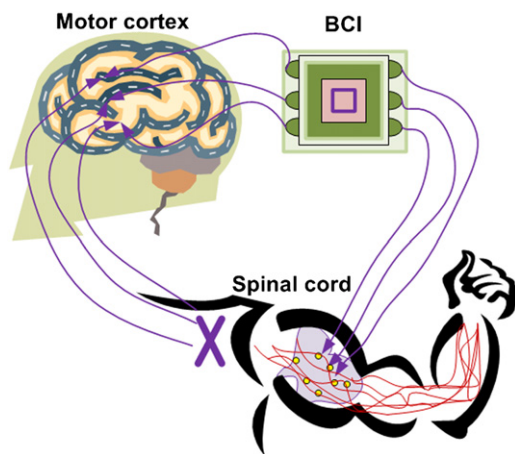
**Fig. 3.** BCI for spinal cord injury.



**Fig. 4.** 6LoWPAN protocol stack.

connection that operates continuously during normal behavior. This recurrent brain–computer interface creates an artificial motor pathway that the brain may learn to use to compensate for impaired pathways, as shown in Fig. 3. One potential clinical application is to bridge lost biological connections. Researchers have shown that monkeys can learn to bypass an anesthetic block in the nerves of the arm and to activate temporarily paralyzed muscles with activity of cortical neurons. BCIs are very promising in direct brain control of external devices. In Velliste et al. (2008), it is shown how primates restore self-feeding by controlling a 3-D robotical arm using their motor cortical activity. Another application is the promotion of neural plasticity to strengthen weak connections and rescue some impaired brain functions. It can help people move or speak again after a stroke or brain injury.

In addition, the company Berkeley Bionics has introduced eLEGS, an untethered exoskeleton, which allows wheelchair users to stand and walk. The exoskeletons are wearable, artificially intelligent bionic devices, which consist of a robotic frame controlled through crutches. The crutches contain sensors; putting forwards the right crutch moves the left leg, and vice versa.

*2.1.3.2. Body sensors and RFID technology.* Some paralyzed patients must wear a diaper when they are in bed. A wetness sensor can immediately alert nurses and caregivers to replace the diaper as soon as it becomes wet (Yang et al., 2008). The detected signal is sent towards a reader using an RFID reader.

### 2.2. Network layer

This layer (see Fig. 1) enables the access of the monitoring stations to the radio channel to transmit the information obtained from the perception layer. Although the Internet protocols were originally designed for fixed networks, there is a growing need for these protocols to accommodate mobile networks, as demonstrated by the use of many different wireless access technologies in IoT (EU FP7 Project CASAGRAS, 2009). The different transmission media include Wireless Local Area Networks (WLANs) (IEEE 802.11 variants), Worldwide Interoperability for Microwave Access (WiMAX) (IEEE 802.16), Bluetooth (IEEE 802.15.1), Ultra-wideband (UWB) (IEEE 802.15.4a and ECMA-368), ZigBee (IEEE 802.15.4), General Packet Radio Service (GPRS) and Wideband Code Division Multiple Access (WCDMA). Wireless ad hoc networks are a good option to establish wireless and mobile communications within the IoT, since they do not rely on a preexisting infrastructure, they require minimal configuration and are deployed quickly with low cost. Networks composed of different access technologies are known as *heterogeneous networks*
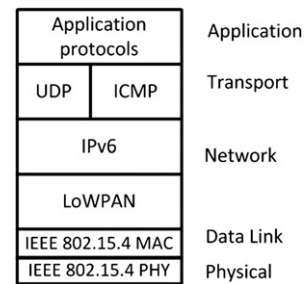
and they should maintain connectivity and service for different applications even with user mobility.

The convergence of heterogeneous networks and applications is possible due to the existence of a single Internet Protocol (IP)-based network. The IP for Smart Object (IPSO) Alliance is a non-profit association of more than 50 members from leading technology, communications and energy companies. They advocate the use of IP networked devices to build the IoT (Dunkels and Vasseur, 2010). They stress that IP is a long-lived and stable communication technology that supports a wide range of applications, devices and underlying communication technologies. In addition, the end-to-end IP architecture is lightweight, highly scalable and efficient. Furthermore, the authors of Internet Ø also recommend the use of the IP protocol to offer the Internet's interoperability and scalability directly to embedded devices rather than needing gateways for protocol conversion (Gershenfeld and Cohen, 2006).

It is necessary to ensure the connectivity, interoperability and compatibility of heterogeneous networks. The low-power networking industry, from ZigBee ad hoc control to industrial automation standards (e.g. ISA100), is quickly converging to the use of IP technology (Shelby and Bormann, 2009). In this sense, 6LoWPAN is the name of a working group of the Internet Engineering Task Force (IETF) that has developed a set of Internet standards, which enable the efficient use of IPv6 over Low-power Wireless Personal Area Networks (6LoWPANs). 6LoWPAN enables resource-limited embedded devices (often battery-powered) in low-power wireless networks to be Internet-connected by simplifying IPv6 (header compression of IPv6 header fields) and taking the nature of wireless networks into account.

The IPv6 protocol stack with 6LoWPAN is shown in Fig. 4. A small adaptation layer (named the LoWPAN adaptation layer) has been defined in the 6LoWPAN protocol stack (see Fig. 4) to optimize the transmission of IPv6 packets over IEEE 802.15.4 and similar link layers (Shelby and Bormann, 2009). IEEE 802.15.4 is a standard that defines the physical and MAC layers for low-power, low-rate wireless embedded radio communications at 2.4 GHz, 915 MHz and 868 MHz.

The adoption of Internet protocols by wireless embedded devices is challenging due to several reasons (Shelby and Bormann, 2009):

- Battery-powered wireless devices require low duty cycles, whereas IP is based on always connected devices.
- Multicast is not supported natively in IEEE 802.15.4 but it is essential in many IPv6 operations.
- Sometimes it is difficult to route traffic in multi-hop wireless mesh networks to achieve the required coverage and cost efficiency.
- Low power wireless networks have low bandwidth (20–250 kbit/s) and frame size (IEEE 802.15.4 packets are rather small, 127 bytes maximum at the physical layer, minus MAC/security and adaptation layer overhead). On the other

hand, the minimum datagram size that all hosts must be prepared to accept, for IPv6 is 1280 bytes. IPv6 requires that every link in the Internet has a Maximum Transmission Unit (MTU) of 1280 bytes or greater. On any link that cannot convey a 1280-byte packet in one piece, link-specific fragmentation and reassembly must be provided at a layer below IPv6.

- Standard protocols do not perform well in low-power wireless networks. For example, TCP performs very poorly in wireless networks due to its inability to distinguish between packet losses due to congestion and those due to channel error.

6LoWPAN is a group of Internet standards created to tackle all these problems. It implements a lightweight IPv6 stack adapted to low-power wireless devices and a Neighbor Discovery (ND) especially well-suited for low-power wireless mesh networks (Shelby and Bormann, 2009).

Routing and addressing are essential IoT networking issues. In Leal and Atzori (2009), scenarios where two or more gateways connect a Mobile Ad-hoc Network (MANET) of objects with the Internet (Multi-homed Hybrid MANETS) have been analyzed. A subnetwork is formed by MANET objects that share a common prefix announced by the closest gateway during address allocation. Gateway selection, dynamical address reallocation and routing changes when objects move from one subnetwork to another have been investigated. The network performance with respect to the packet delivery ratio, the end-to-end delay and the jitter with two different MANET routing protocols (AODV and OLSR) has been analyzed.

In addition, the IETF has developed an IPv6 routing protocol for Low power and Lossy Networks (LLNs) (including 6LoWPAN (Atzori et al., 2010)), that is, the RPL routing protocol (Clausen et al., 2011). LLNs are formed by smart objects with limited processing power, memory and energy (battery power). Unlike the MANET routing protocols, which perform well for ad hoc networks, RPL is optimized for upstream and downstream routing to/from a root node, a paradigm very appropriate for networks connected to the Internet. This routing protocol is essential for the deployment of IoT, since it enables traffic to be forwarded between low-power devices and the Internet. It has been designed assuming that the LLNs can comprise up to thousands of nodes and they are interconnected by unstable (lossy) links. The IETF Routing Over Low power and Lossy networks (ROLL) working group has defined application-specific routing requirements after focusing on a wide number of IoT applications: urban networks including smart grid, industrial automation, home and building automation. We also expect that this protocol is suitable for the IoT applications for handicapped people. Furthermore, RPL has been designed to operate over a variety of link layers such as IEEE 802.15.4.

RPL (Clausen et al., 2011) is a distance vector IPv6 routing protocol for LLNs. A Directed Acyclic Graph (DAG) is a graph having the property that all edges are oriented in such a way that no cycles (paths starting and ending on the same vertex) exist. All edges are contained in paths oriented toward and terminating at one or more root nodes (traditionally named sinks in Wireless Sensor Networks (WSNs)). RPL routes are optimized for traffic to or from one or more roots (sinks in WSNs). As a result, RPL uses the DAG topology and is partitioned into one or more Destination Oriented DAGS (DODAGs), one DODAG per sink. RPL specifies how to build the DODAG using an objective function and a set of routing metrics/constraints. The objective function computes the best path according to certain routing metrics and constraints. This way, DODAGs with different characteristics can be built. For example, different DODAGs are constructed with the objective to (1) find the best path in terms of link throughput (metric) while avoiding battery-operated nodes (constraint) or (2) find the best

path in terms of latency (metric) while avoiding non-encrypted links (constraint). There could be several objective functions operating at the same node depending on the different path requirements of a given traffic. This way, it is possible to have multiple topologies (DODAGs) active at the same time to carry traffic with different requirements. The objective function also dictates some rules of the DODAG formation (number of parents, how to select them, load balancing, etc.). More details about RPL can be found in Clausen et al. (2011).

## 2.3. Application layer

This layer (see Fig. 1) provides an *operation support platform*, which can be accessed by monitoring stations and applications. It provides important functionalities such as authentication, billing, service management, service acceptance and routing of packets based on defined policies. IP Multimedia Subsystem (IMS) is a transport platform well-suited to perform these functions (Domingo, 2011), since services can be offered to the subscribers independently of the access media used, heterogeneous networks can be easily integrated and new applications and services can be rolled out faster reusing well defined common functions such as authentication, service provision, billing, group management and presence. This way, the IoT can be uniformly managed.

The Web of Things (WoT) is a vision where smart objects are integrated with the Web. Smart object applications can be built on top of Representational State Transfer (REST) architectures (Fielding and Taylor). The REST architectural style decouples applications from the services they provide, which can be shared and reused. The key abstractions of information in the REST architecture are resources (e.g. a document or image). Resources in web-based REST systems are identified by Universal Resource Identifiers (URIs). REST-style architectures consist of clients and servers. Clients initiate requests to servers; servers process these requests and return the appropriate responses. Resources are accessed by clients using methods such as GET, PUT, POST and DELETE of Hypertext Transfer Protocol (HTTP). The resources themselves are conceptually separate from the representations that are returned to the client. For example, the server does not send its database, but rather, perhaps, some HyperText Markup Language (HTML), Extensible Markup Language (XML) or JavaScript Object Notation (JSON) that represents some database records depending on the details of the request and the server implementation.

A web service is a software system designed to support interoperable machine-to-machine interaction over a network. Web services enable the communication between processes applying REST for the manipulation of resources using HTTP, or Simple Object Access Protocol (SOAP) for sending messages and making Remote Procedure Calls (RPCs) in a distributed environment.

However, the technologies deployed for web services are not appropriate for constrained networks and devices (Shelby, 2010). The protocols used to realize RESTful web services have several serious problems when applied to constrained networks. HTTP headers are frequently too large and require fragmentation in 6LoWPAN networks (using IEEE 802.15.4). TCP is not well-suited for wireless networks, the HTTP request/response pull model (request initiated by the client) does not work well in sensor networks with very low duty cycles and HTTP, as currently used between modern servers and browsers, has evolved into a highly complex protocol. Therefore, the RESTful web service paradigm needs to be extended.

The Internet Engineering Task Force (IETF) Constrained RESTful environments (CoRE) working group has defined a REST based web transfer protocol called Constrained Application Protocol
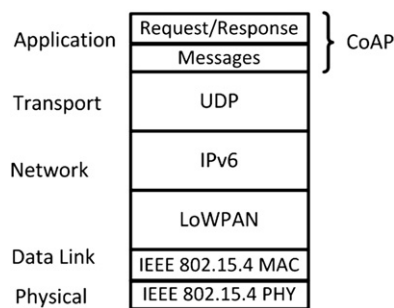
**Fig. 5.** CoAP protocol stack.

(CoAP) (Shelby et al., 2011). The aim of CoAP is to extend the REST architecture for constrained IoT devices and networks (e.g. 6LoWPAN). It has been designed taking into account the requirements of important Machine-to-Machine (M2M) applications such as energy and building automation. We also think it is appropriate for the IoT applications for people with disabilities. CoAP consists of a subset of REST common with HTTP functionalities, which have been optimized for M2M applications. CoAP offers features for M2M applications such as very low overhead, multicast support and asynchronous message exchanges.

The CoAP protocol stack is shown in Fig. 5. Unlike HTTP, CoAP exchanges messages asynchronously over a datagram-oriented transport protocol such as User Datagram Protocol (UDP). TCP is not well-suited due to its bad performance in LLNs, sensitivity to mobility, no multicast support and high overhead for short-lived transactions (Shelby, 2010). Since CoAP is built on top of UDP, its overhead is lower and it supports efficient IP multicast. Since UDP is non-reliable, CoAP implements a lightweight reliability mechanism, without trying to re-create the full feature set of TCP.

CoAP is divided into two layers (Shelby et al., 2011): the messaging and the request/response layer. The messaging layer deals with the asynchronous exchange of messages over UDP between end-points. There are four different types of messages: Confirmable (CON) (these messages require an Acknowledgment (ACK)), Non-confirmable (NON) (they do not require an ACK), Acknowledgment (ACK) (they acknowledge a confirmable message) and Reset (RST) messages (they indicate that a confirmable message was received, but some context is missing to properly process them). The Request/Response layer handles the transmission of requests and responses for resource manipulation and transmission. A request is carried in a Confirmable (CON) or Non-confirmable (NON) message. The response to a request in a CON message is carried in the resulting ACK message. The reliability mechanism consists of a simple stop-and-wait retransmission protocol with exponential back-off for "confirmable" messages between retransmissions. It detects both "confirmable" and "non-confirmable" duplicates and it supports multicast.

CoAP uses a short fixed-length header (4 bytes) that may be followed by options (e.g. URI and payload content-type) and a payload. This way, the overhead is significantly lower than in HTTP with the purpose of limiting fragmentation.

In the application layer the services are run by application servers, which host and execute the services and provide the interface to communicate with the operation support platform. We have identified some important application servers in the IoT for people with disabilities (see Fig. 1). The *RFID application server* is useful in the *navigation system for blind* application. It receives tag information concerning the current location and destination of the blind person. The best route is computed using the shortest path algorithm. When a user is lost, the tags in the way help to detect it and a new route towards the destination is computed

based on the current location. This route is sent back to the monitoring station using the IP network. The RFID database stores and updates data concerning the user, his/her path achievement, destination changes and path preferences.

The *monitoring application server* offers application codes (such as Ajax) to process the sensed data the disabled person/professionals wish to control. Periodic reports and visual graphs are sent to the monitoring station of the user. The sensor nodes transmit the sensed data via web services according to the disability and/or preferences of the user. For instance, the doctor of a paralytic might want to control periodically the state of the BION sensors or a nurse the wetness sensor data of diapers; a deaf person might be interesting in reviewing the alarm reports of his/her smart home.

The signaling Web 2.0 gateway (see Fig. 1) interconnects the transport platform and the Web 2.0 domains. People with disabilities can access Internet to search for real-time information (e.g. location of an open restaurant or a free parking lot for handicapped) or to keep contact with relatives/friends using social networks.

## 3. Application scenarios

Next, several application scenarios of the Internet of Things for handicapped people are introduced. They illustrate the interaction of the different components of the IoT architecture.

### 3.1. Shopping scenario

In this scenario, people with visual impairments shop autonomously as shown in Fig. 6. The *blind navigation system* helps them to find their way in a store. The store's RFID system can use software to guide the visually impaired in shopping. In López-de-Ipiña et al. (2011), an RFID-tag based navigation system is proposed. The supermarket is divided into cells containing a shelf and passageway cells. RFID tags are distributed through the floor. The tag IDs within a cell are mapped to navigation information such as the type of a given cell and the types of neighboring cells. The monitoring station (smart phone) maintains a Bluetooth connection with the RFID reader (smart cane) of the user to keep track of his/her position anytime using the mapping of tag IDs with navigation information. The speech synthesis and recognition module of the monitoring station (smart phone) enables the visually impaired person to say the section of the supermarket where he/she wants to go. The route to follow is obtained invoking web services through a WLAN connected to the Internet. As the visually impaired walks, routing directions from an android application are received through the headphone of the smart phone and played as voice messages.

RFID tags attached to the supermarket products supply product data such as name, description and price. Sensor enabled RFID tags provide essential data such as temperature or shocks during transportation. The tag reader (RFID cane) transmits the tag ID string to the monitoring station, which forwards it to the RFID server (Krishna et al., 2008). Product information is returned from the RFID database to the monitoring station and played as voice messages. Additional product characteristics can include food composition, caloric intake and specific data related to the user profile such as food allergies and intolerances. Friend's opinions about the product and price comparison with similar ones can be obtained using social networks. In Krishna et al. (2008), experiments of the RFID system were conducted to study detection range of RFID readers with respect to different tags and materials (where the tag is installed); it was concluded that the
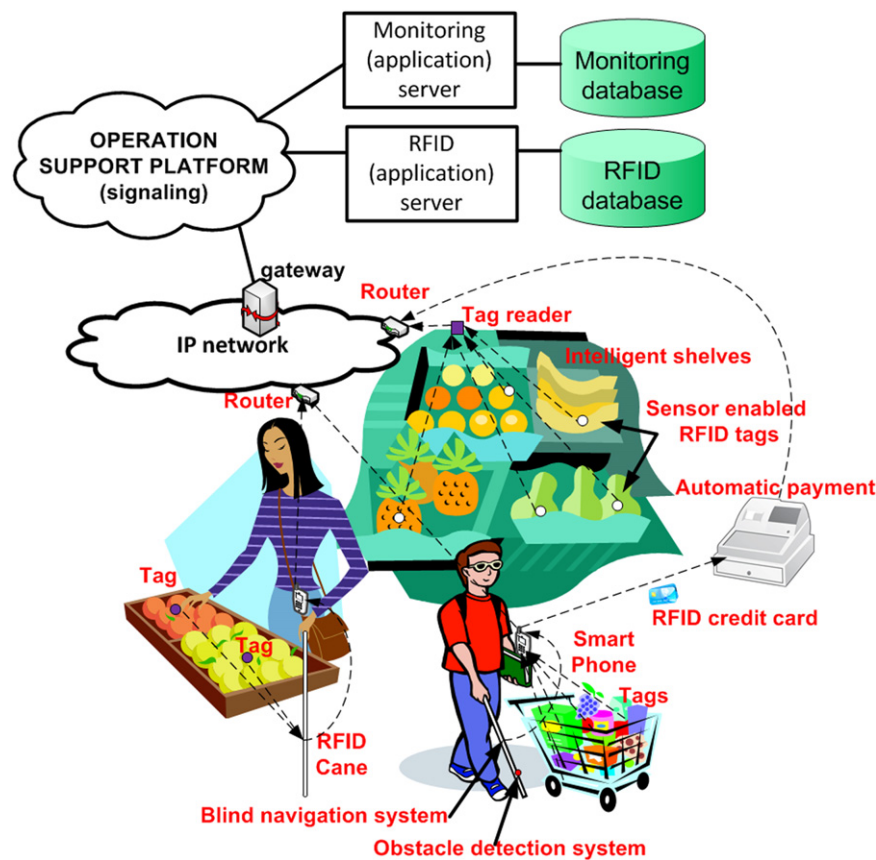
**Fig. 6.** Shopping scenario.

product materials did not affect the performance of the RFID readers.

Several practical works have been developed related to this application scenario (Kulyukin and Kutiyanawala, 2010; Lanigan et al., 2007; Narasimhan, 2006; Nicholson et al., 2009; Winlock et al., 2010). In Lanigan et al. (2007) the authors propose Trinetra, a system designed to assist blind people in grocery shopping for product search and identification. As the visually impaired scans a grocery item with a portable barcode or RFID reader, the scanned input is sent via Bluetooth to the user's smart phone, which checks its cache for a product match. In case of cache miss, the smart phone communicates through GPRS with a remote server or, in case of miss, with a public Universal Product Code (UPC) or RFID database, which converts the barcode or tag into a human-interpretable product name (and related information) and returns it to the smart phone. An onboard text-to-speech software in the smart phone converts the displayed text into speech. The advantages of RFID tags compared to barcodes are reprogrammability, ability to contain more product information and ability to read without line-of-sight reading (Narasimhan, 2006). Trinetra was successfully tested at the Carnegie Mellon University's campus store.

ShopTalk (Nicholson et al., 2009) is a wearable system to assist visually impaired shoppers. The users get verbal instructions from a handheld computer. Modified Plessey (MSI) barcodes located on the shelves enable navigation within the store. UPC barcodes enable product localization in a store aisle. In a production version, the system would connect to the store's inventory control database and look up product information. Successful experiments with visually impaired participants were performed at supermarkets.

GroZi (Winlock et al., 2010) focuses on real-time product detection from mobile video in grocery stores. A user compiles a shopping list of products on the website and uploads it on a portable device. Later, the shopper scans a scene in the supermarket with a camera. GroZi uses in vitro images of items (images of products taken under ideal lighting and perspective conditions) on the user's shopping list to detect items in situ (from actual video stream). A hand glove with vibrating motors and the audio of the portable device are used to guide the shopper. The capability of detecting a shopping list's items is demonstrated with experiments.

Automatic payment can also be performed using RFID. A scanner reads all items in the cart at once, totals them up and charges the customer's account while adjusting the inventory. RFID credit cards use a radio frequency to transmit personal financial data.

Furthermore, periodic reports and statistics concerning the shopping can be computed and sent periodically from the monitoring server to the monitoring station.

### 3.2. At school

The school scenario is shown in Fig. 7. The authors in Hengeveld et al. (2009) show the great added value of designing intelligent interactive play and learning environments for toddlers (from one and half to four years old) with multiple disabilities to stimulate their language and communication skills. These play and learning systems include RFID technology to identify different materials (such as a child's toy sheep). On the other hand, RFID-tagged toys are used to help deaf kids ages three to four learn how to use sign language (Parton et al., 2010). The software developed enables a child to use a RFID reader to scan an item's tag, capture the unique identifying number and send it to the computer's software via the USB connection. An animation is launched, which includes videos of a person and of an avatar
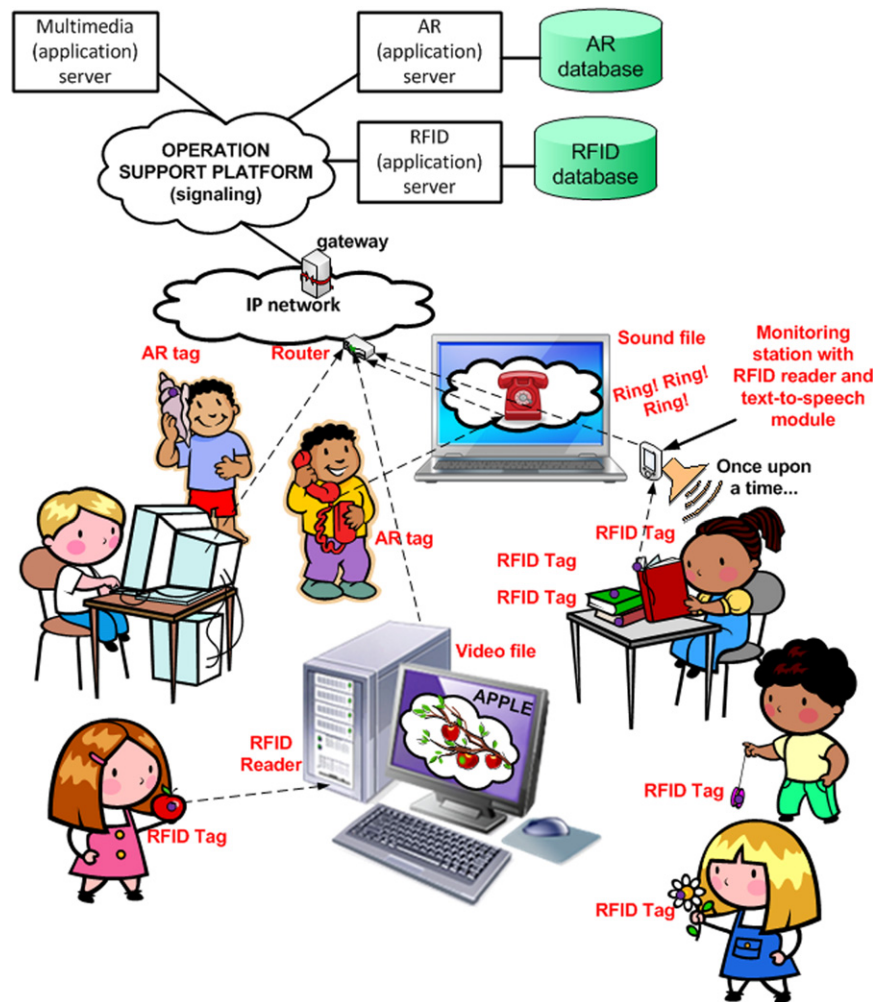
**Fig. 7.** School scenario.

signing that item (in American Sign Language (ASL)) as well as several pictures of the item to familiarize the child with the many versions of the object (e.g. multiple types of ships). The concept is also shown in written English for a bilingual approach to language acquisition. The system was integrated into the early childhood curriculum at the Louisiana School for the Deaf for four weeks to determine its impact on vocabulary acquisition, and the results were positive (Parton et al., 2009). In addition, the authors in Parton et al. (2010) concluded that low cost RFID tags/readers were more appropriate than low cost barcode reader/tags for this educational setting (tested with K-6 students in elementary school), since 99% of the students were able to launch the animations successfully with the RFID reader/tag and only 26% with the barcode reader/tag. Furthermore, success was obtained with RFID technology instantly (1–15 s to successfully scan) in 96% of the launched animations. Currently, information concerning the tagged objects is stored on a computer. However, the application could be managed more efficiently using a RFID server and database; the multimedia videos could also be stored and downloaded by an application server. We also suggest that more than one object could be scanned at the same time by the tag reader to establish associations between different objects and their nouns. In this case, a new multimedia video would be launched signing and including examples of the objects altogether. In addition, single-microchip tags could be attached to the same object (RFID grid). For instance, a doll with tags attached at different body parts could be

scanned by the reader to launch different instructive videos. This way, children could learn to identify the different body parts.

We also propose to go one step further and extend this technology to zoo or farm visits where children with tag readers and monitoring stations could learn concepts looking at real things (true apple or elephant instead of plastic ones). The tag reader would communicate to the monitoring station the tag ID string of the scanned object, which would forward this information to the RFID server. Information concerning the scanned object is returned from the RFID database to the monitoring station and a multimedia video would be played.

Augmented Reality (AR) combines real world and computer generated scenes. Its major components are tags, a web-cam and image processing devices. A program is launched on a computer to recognize real AR objects. This program is able to obtain the tag ID from real AR objects and locate them in a database. It is possible to watch the objects on the screen, launch a sound file in real-time, etc. For instance, a picture card can contain an AR tag. The AR image processing device recognizes the picture card when it appears on screen and uses the tag to identify the picture card type. The corresponding sound (e.g. a telephone ringing) is then introduced to realize the merging of virtual sound with real imagery (Chien-Yu et al., 2010). This way, sensory or mentally handicapped children can learn common everyday sounds. Using the feel of different material supplemented by audio explanations allows visually impaired children to learn about different

materials and experience them through their sense of touch (Chien-Yu et al., 2010). Studies (Chien-Yu et al., 2010) with physically challenged children from kindergarten to first grade demonstrated that AR is a highly effective assistive technology. Other AR applications allow children to handle 2D and 3D plant entities (fruits, flowers, leaves, seeds) (Richard et al., 2007). They should reach for and handle a given entity (located on a tangible marker) and position it at the location instructed by the AR system. Visual (entities surrounded by a red/blue circle are wrong/right positioned), auditory (names of the entities are played using audio) or olfactory (odor of the entity) cues are provided to help them in decision-making.

In addition, children with visual impairments can locate specific books using RFID technology and 'read' them using the text-to-speech module of a monitoring station (see Fig. 7). In Parton and Hancock (2011), ongoing research on the use of RFID embedded storybooks with deaf children is presented. Videos depicting a story in ASL are launched in a computer every time the deaf children scan the tags of the book pages. The study conducted with a prototype was very successful, and both teachers and deaf students showed very positive reactions.

### 3.3. Domestic environment

Smart home technology (see Fig. 8) refers to the integration of technology and services through home networking for a better quality of living. Smart homes enable the *automation and control of the home environment* using multiple devices such as automatic kitchen equipment, light and door controllers, indoor temperature controllers, water temperature controllers and home security devices (Stefanov et al., 2004). These *home devices for automation and control* are formed by sensors and actuators embedded in goods, home appliances or furniture. The sensors monitor the environmental conditions, process collected information and cooperate with other



**Fig. 8.** Smart home scenario.
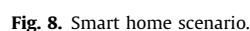
units through a wireless network. The collected information is then processed by a server to provide suitable services to the user. If events that give rise to alarm conditions are detected, actuators are triggered for handling the current emergency situation (e.g. burglar or fire alarm).

The integration of RFID in the smart home environment is also essential for identification and tracking purposes. In Darianian and Michael (2008), a master–slave RFID architecture is proposed. Slave readers integrated in the home appliances communicate with mobile readers (monitoring stations) and a master reader, which is connected to a smart home server. Different master readers can communicate with each other and the mobile readers. This system is applied to home washing control as shown in Fig. 8. RFID tags attached to clothes contain information about color, material and suitable washing program. If the amount of dirty clothes detected by a RFID reader reaches a threshold, an alarm is automatically sent and an energy-aware washing program is suggested. The reader also checks the compatibility between clothes when the washing machine is being loaded. The dirty clothes left for the next washing are also monitored with the aid of the smart home server and a database. Other smart home applications combine Internet services with RFID identification. The slave readers in the fridge and shelves communicate to a master reader in the kitchen to suggest cooking recipes based on the resident's preference and his/her health conditions (food allergies or cholesterol), invoking web services that supply recipe search and download. The health monitoring server and database are useful to monitor and record the health conditions of the resident. The smart home server and database are also useful to record the resident's list of required food items and the current availability of these items to compare them and generate a shopping list automatically.

Furthermore, an automation logic is proposed in Buckl et al. (2009) to optimize the power consumption throughout the day, According to the price of electricity obtained from an external web service, the energy consumption in the house is diminished (e.g. disconnecting the house from the power grid and using energy from a battery, putting the refrigerator in an energy saving mode until a temperature threshold is met, etc.). A future home automation scenario is developed in Buckl et al. (2009) for demonstration purposes.

Modern sensor-embedded houses or smart houses can assist impaired people and resolve their social isolation (Chan et al., 2008). Smart homes are adapted to people with disabilities in two different ways: (1) *specific interfaces* are designed to manipulate *the home devices for automation and control* and (2) *special assistive devices* are specifically designed to improve their living conditions at home.

The *specific interfaces* required to assist disabled people in the control of smart homes are summarized as follows (Stefanov et al., 2004):
Visually impaired people require:

- Specialized Human Machine Interface (HMI): it refers to the operational subsystem to control home equipment (lamps, TV sets, doors, etc.). Specialized zooming devices (both optical and optoelectronic) allow people with low vision to control the home environment. A retinal prosthesis (Schwiebert et al., 2001) can also enhance their vision (see Section 2.1.1). Voice control of home-installed devices is also a proper method.

Hearing impaired people require:

- Specialized HMI: touch screens to access graphical information and read text. Assistive devices for deaf are helpful (see Section 2.1.2).

Physically impaired people require:

- Specialized HMI: people affected by serious paralysis can use head-tracking devices to produce up to three independent proportional signals (forward–backward head tilting, left–right head rotation and lateral head tilting). Other techniques involve facial detection, eye-movement control, brain control, gesture recognition and facial expression recognition. In Sun Ju et al. (2009), an intelligent wheelchair is proposed; it determines its direction based on the inclination of the user's face and is stopped depending of the shape of the user's mouth.

Some examples of *special assistive devices* required to assist disabled people in improving their living conditions at home are summarized as follows:
Visually impaired people require:

- Devices for indoor navigation: a navigation system (Saaid et al., 2009) and an *obstacle detection system* (Martin et al., 2009) based on voice-synthesized instructions are valuable (see Section 2.1.1).

Physically impaired people require:

- Electro-mechanical devices for movement assistance: typical devices include powered wheelchairs and specialized lifting devices to transfer the user between the bed and the wheelchair. In Ahmad and Tokhi (2011), a two-wheeled wheelchair able to lift the front wheels (casters) to achieve an upright position has been designed. This way, the disabled persons who cannot stand on their own can reach certain heights and are able to pick and place things on shelves.
- Robotic systems for movement assistance: rehabilitation robots are designed to assist individuals in their everyday needs, such as eating, object replacement, etc. In Satoh et al. (2009), a method for bathing care assistance using the robot suit HAL is introduced.

These special assistive devices can also include specific Human Machine Interfaces (HMIs) (if necessary) to allow handicapped people to control them.

An important RFID-based application especially useful to provide a better quality of life for visually impaired people at home is a *search engine* to find objects (Welbourne et al., 2009). Personal objects are labeled with RFID tags. Metadata containing object-related data is created such as name, type, image URL or last registered location. Sensory context information (such as temperature) can also be acquired with the aid of sensors. All this information is introduced and managed with a web-based tool. This way, physical objects are linked to virtual ones. Different RFID readers are set at specific home locations. Another web-based tool is used to specify how to transform a user's tag-read event into high-level information. Labels such as 'with', 'without', 'near', 'far', 'inside' and 'outside' help to link tagged objects with people, places and events. For instance, a RFID reader can register the user leaving the house 'with' the wallet. This way, the last recorded location of a tagged object can be found. Users can be notified when they leave home 'without' a particular item (with a voice-synthesized message if they are visually impaired people). A four-week study was successfully conducted to measure trends in utilization of the designed RFID tools and applications as well as users' qualitative reactions. A different RFID reminder tool has been developed in Hsu et al. (2011). It compares the objects taken by the user when he/she leaves home with an object list generated by the system based on a calendar and the user's activities. The application sends a warning message to the PDA of

the user when he/she leaves home and one or more objects theoretically needed are missing. Experiments were successfully carried out with a prototype of the system.

## 4. Benefits of the IoT for disabled

Environments can foster the participation and inclusion of disabled individuals in social, economic, political and cultural life (World Health Organization (WHO), 2011). The IoT creates enabling environments by offering people with disabilities assistance in building access, transportation, information and communication.

Next, the benefits of the IoT for handicapped people are discussed. We focus on the benefits of applying the IoT in the application scenarios described in the previous section.

The IoT applied to smart homes or shopping scenarios makes it easy for people with impairments to carry out their daily activities. This increases their autonomy and self-confidence. Being independent in one's daily activities without requiring assistance from a sighted person is the highest priority for the visually impaired (Lanigan et al., 2007); applying IoT to shop autonomously fulfills these needs. In addition, smart homes offer disabled people independence in mobility, object manipulation and human–machine interfaces (HMIs) for communication. Home automation carries out certain daily activities (e.g. lighting control) automatically for them. Furthermore, monitoring systems improve the autonomy of handicapped people at home, since they reduce or eliminate control visits of caregivers.

On the other hand, sensory or mentally handicapped children can use interactive play and learning IoT environments ('at school' scenario) to experience a richer learning experience (cognitive skill development), have more opportunities for language acquisition (linguistic skills), become better at interacting with others (social skill development) and thus obtain higher self-esteem (emotional skill development) (Hengeveld et al., 2009). In addition, these interactive IoT systems adapt to their learning rhythm. For instance, deaf children often need additional exposure to the American Sign Language because most on their parents are hearing and not fluent in this language (Parton et al., 2009). Now they can take this interactive IoT system with them from school to home and repeat the most difficult vocabulary until they understand and memorize it. Learning is less difficult with this innovative and friendly system (it turns into a game) and learning barriers are reduced. This fact is especially important, since there is a strong correlation between early signed language exposure for deaf children and later academic achievement (Parton et al., 2009).

## 5. Research challenges

Next, the research challenges to IoT for people with disabilities are introduced.

A key challenge *is customization for people with disabilities*. Since handicapped people have special needs, the IoT should be adapted to their particular circumstances. Smart workflows are context-aware processes that are executed pervasively. They take context-aware decisions based on context information of the environment captured automatically by sensors. The authors in Wieland et al. (2008) describe an architecture that converts low-level context-aware information captured by sensors into information at the business level using smart workflows. Developers use business process modeling tools to describe smart workflow tasks. Presto is a model-based (Giner et al., 2010) software architecture that captures the concepts that are involved in the interaction between physical elements and their digital counterparts. When the business models are deployed in an execution engine, humans are usually required to perform some tasks in a workflow. Presto's architecture processes these demands and offers the appropriate mechanisms for users to complete these tasks by enabling their interaction with the physical world. The resulting system is capable of presenting to each participant in the process the services associated with his/her context (physical environment) according to his/her role and current pending tasks. This way, the user is guided through a workflow. For example, if a library member with a monitoring station (PDA) enters the library, Presto shows in the monitoring station the tasks that the user can initiate and complete depending on the available task processors. We propose that if the user is disabled, the list of tasks is received in an appropriate way. For instance, the return boxes of the library automatically detect the returned books by means of RFID. If the disabled person selects the 'return book' option, different ways to orient the user towards the closest return box according to his/her disability should be provided (visual or auditory related information, indications for paralytics about how to access the area where the return box is, etc.).

Another significant challenge to the IoT for people with disabilities is *self-management*. It refers to the process by which the IoT manages its own operation without human intervention. For this purpose, support for *self-configuration*, *self-healing*, *self-optimization* and *self-protection* capabilities is required (Haller et al., 2009). Self-configuration is related to the automatic configuration of components; self-healing handles the automatic discovery and correction of faults; self-optimization focuses on the automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements; self-protection tackles the proactive identification and protection from arbitrary attacks. Self-healing is particularly important, since handicapped people usually depend on IoT devices to compensate for their disabilities. Therefore, the detection and elimination of faulty nodes and the design of efficient fault-tolerant algorithms are required.

*Standardization* is also a very important challenge. It is necessary to create globally accepted standards to avoid *interoperability* problems. 6LoWPAN provides wireless internet connectivity to low-power devices with limited processing capabilities, so that they can be used in the IoT. As a result, with this standard, interoperability and integration with current heterogeneous Internet-aware devices is accomplished to expand the IoT for disabled people. On the other hand, existing mobility protocols like Mobile IP for IPv6 (MIPv6) or management protocols like Simple Network Management Protocol (SNMP) cannot be directly applied to 6LoWPAN devices, since they are inefficient in terms of energy, communication and computation cost (Jara et al., 2010). Therefore, more research to adapt existing protocols or find new solutions is required.

Furthermore, enabling people with disabilities to establish deeper contact with the outside world is challenging. IoT objects can automatically share pictures, comments and sensor data via social networks. For instance, relatives of a disabled person that belong to the same social network can obtain real-time data about the activities of the handicapped person (if he/she is sleeping, eating, leaving home, has fallen, etc.). This information is automatically sent by 'smart objects' that surround the disabled person in his/her domestic environment (smart home) (Kranz et al., 2010). Although direct communication with devices via social networks seems to be an exciting and promising way of maintaining social contact, the possibility of *machines flooding social networks* with auto-generated content exists.

The amount of traffic in the IoT will rise exponentially once connections between most objects are established in the next

years. *Scalability* is required to guarantee the proper functioning of the IoT with a very high number of nodes. Senseless communications between 'things' should be avoided to favor scalability, since they increase the communication overhead and energy consumption. However, a minimum number of connections between devices should be established for the proper functioning of applications (such as enough tag density and messages to orient a blind person).

In addition, *security and privacy issues* are real (Zorzi et al., 2010). It is essential to guarantee the privacy of the IoT for people with disabilities, who are particularly vulnerable. The IoT should be protected against distributed denial-of-service attacks, which can be defined as the result of any action that prevents any part of the IoT from functioning correctly or in a timely manner. The vulnerabilities of applications and sensors are exploited to launch such attacks. Consequently, an efficient security framework should be developed.

*Cooperation* between devices in the IoT is also indispensable (Zorzi et al., 2010). Scenarios where more capable nodes (monitoring stations) discover other resource-restricted nodes, synchronize with one another and help each other in reliable data delivery seem very promising. Nowadays, most IoT mass consumer applications are mobile devices-centered, since monitoring stations are more likely to integrate sensing, computing and communication capabilities. However, we envision that over time more direct thing-to-thing connections (between 'things' that are currently considered resource-restricted) will be established as communication, processing capabilities, technologies deployed for web services and energy harvesting techniques evolve.

Finally, we envision that the IoT for disabled people (especially physically disabled individuals) will evolve dramatically in the following years. The advances of brain–computer interfaces (BCIs) made possible the development of prototypes such as brain-controlled prosthetic devices, wheelchairs, keyboards and computer games. In the following years BCI technologies will be brought out of the lab and transform into real-world applications (Millán et al., 2010). Disabled people will benefit from the *advancements in BCI technology combined with assistive technologies* in four basic application areas (Millán et al., 2010): communication and control (Internet browsing, e-mails), motor substitution (in particular grasping and assistive mobility), entertainment (gaming, music browsing, photo browsing and virtual reality) and motor recovery. Neurophysiological signals (electroencephalogram, EEG) originating from the brain will be used to control external devices (e.g. TV, phone, computer, bed), which means human beings will be fully embedded in the Internet of the Things.

## 6. Conclusion

In this paper, an overview of the IoT for people with disabilities is provided. The relevant application scenarios and main benefits have been described. The research challenges have also been surveyed. These research issues remain wide open for future investigation.

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