The authors analyze the characteristics of wearable applications for Internet of Things scenarios and describe the interaction patterns that should occur between wearable or mobile devices and smart objects.

Over the past few decades, the Internet has grown to allow people to access and consume services on a global scale using traditional hosts and always-connected mobile devices such as smartphones, typically over the World Wide Web. By connecting objects and devices, the Internet of Things (IoT) will fully exploit networking’s potential and enable the application of innovative services to a large set of scenarios, such as home and building automation, smart cities, and healthcare. This will integrate new paradigms for human-to-machine (H2M) and machine-to-machine (M2M) interaction. Many IoT applications will let users interact with smart environments that provide them with information and change and adapt according to their needs and preferences, with or without these users in the loop. IoT applications will exploit the large diffusion and pervasive deployment of smart objects—tiny devices equipped with a microcontroller, a communication interface (wired or wireless), a power supply, and a set of sensors and actuators that are used to interface with the surrounding environment.

Several players are developing innovative IoT-related products in a variety of fields even as users are becoming aware of the integration between the physical and cyber worlds. This “gold rush” is driven on one hand by the desire to demonstrate the feasibility of interconnecting everyday devices to people and on the other hand by the intent to make custom solutions possible standards for the general public. This has created a plethora of closed vertical solutions, leading to a highly fragmented market: a babel of incompatible solutions instead of a highly standardized and interoperable environment, which is what the Internet (of Things) should be like. To prevent the IoT from reaching a dead
end due to this fragmentation, many efforts have been carried out in research projects and by standardization organizations such as IEEE, the Internet Engineering Task Force (IETF), and the Internet Protocol for Smart Objects Alliance (IPSO). These activities have two main goals. The first is to define open standards for communication, which currently include IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) and the Constrained Application Protocol (CoAP), with others still in progress. The second is to map the traditional IP-based Internet stack to the IoT. The successful communication model the Web represents is viewed as a reference for the IoT. We can now assume that the IoT will be a network of heterogeneous, interconnected devices that will create the infrastructure for the so-called Web of Things (WoT).

Mobile devices (smartphones and tablets) have become the most popular computing devices in the world; they topped the per-capita rate of personal computer penetration for the first time in mid-2012. We are, in fact, living in a mobile-centric world, characterized by a symbiosis and interdependence between users and their mobile devices, up to the point where one can't work without the other. Thanks to their rich equipment, mobile devices are a handy and ready-to-use gateway to all IoT objects deployed remotely or in their proximity—a cyber “Swiss army knife” for the IoT. The evolution of wearable computing will further foster this paradigm, given its potential to actually augment how people interact with services (for example, through voice control, gestures, or touch) or provide information to services (heart rate monitoring, fitness applications, and so on).

The unifying vocation of mobile devices is therefore twofold: the smartphone enables users who want to control and interact with both smart objects in their proximity and wearable devices. The interaction with smart objects through wearable devices will represent a quantum leap toward a full integration between the social, cyber, and physical worlds, which will be a milestone for widespread IoT adoption. The interaction between wearable devices and IoT objects should occur through well-defined patterns, which must consider their nature while providing maximum usability and the best user experience.

**Interaction Patterns through Wearable Devices**

The evolution of mobile and wearable computing has changed the way people use online services by keeping them always connected, whether at home or on the go. In this context, there’s a concrete need to fill the gap between mobile devices and the IoT. A paradigm shift in specific aspects is required to let people access and use the IoT with the same simplicity experienced when accessing the Internet and, possibly, to enable new and more natural forms of interaction, which will broaden the IoT user base.

**Smart Object Communication Principles**

The idea of an IP-based IoT has been around for years and is now considered fact. The adoption of the IP protocol for smart object addressing and communication will drive the IoT’s full interoperability and integrability with the existing Internet. In particular, the use of IPv6 is foreseen as the solution to managing billions of globally addressable devices. A fundamental principle that has driven IoT research and the work of standardization institutions is the awareness of the many benefits gained by choosing to maximize the reuse of standard Internet protocols and mechanisms. Due to the limitations of low-performance IoT devices, it isn’t always possible to use the traditional TCP/IP protocol stack. New energy-efficient and low-overhead communication protocols and data formats, which consider group communication, mobility, and interaction among multiple devices, have been designed. The introduction of 6LoWPAN has solved the problem of bringing IP to low-power devices. Thanks to the definition of common standards, the IoT is ready to reach the next level: the WoT.

The Web is by far the most popular and familiar interaction model on the Internet. The WoT is being designed around well-known concepts and practices derived from the Web, such as the Representational State Transfer (REST) paradigm. This paradigm has been introduced to loosely couple client applications with the systems that they interact with, support the long-term evolution of systems, and provide robustness. At the application layer, CoAP has been designated as the standard protocol for the WoT, similar to what HTTP is for the Web. In fact, CoAP has been designated to work with HTTP, to which it
maps easily for integration by inher-
ititing resource identification through
URLs, the request/response commu-
nication model, and the semantics of
HTTP methods.

However, it isn’t possible to fully
map CoAP to HTTP for several rea-
sons. In particular, CoAP is a binary
UDP-based protocol, whereas HTTP
implies connection-oriented commu-
nications. CoAP also introduces some
significant enhancements and opti-
mizations that are relevant for low-
power devices, such as the support for
group communication and resource
observation. This latter feature lets
client applications, after an initial
request, receive updates for a given resource in
successive response messages without needing to
perform periodic polling. Resource observation
introduces a new communication paradigm with-
in REST. Note that REST is not the only comu-
nication paradigm that is ever going to be adopted
in the IoT, similar to what happens on the traditi-
onal Internet: protocols using publish/subscribe
mechanisms fit well when a single source delivers
information to multiple receivers.

**Interaction Patterns**

The presence of a smartphone is required when us-
ing wearable devices: it’s the phone’s responsibility
to perform all the heavy and complex tasks (mainly,
processing and communication). Wearable devices are,
in fact, extensions of mobile devices, which act
as a central hub. To enable a truly seamless and
practical interaction with smart objects through
wearable devices, it’s crucial that the smartphone
takes care of these tasks behind the scenes. In
smart environments, wearable devices will thus
play the role of truly enabling natural interactions
with things, more similar to what people expect. As
pointed out by Sergey Brin in a TED talk at the time
Google Glass launched, the use of smartphones
isolates people, who are constantly and obsessively
looking down at their devices, whereas the use of
Google Glass (and of any wearable device, in gen-
eral) would let people keep their heads up, allow-
ing for simpler and more natural interactions. This
is going to have an even bigger impact when users
start interacting with myriad smart objects, rather
than just texting or checking email.

Wearable devices can be classified into two cat-
egories. **Passive wearables** don’t require any direct
human interaction (such as heart rate monitors
and step counters) and are therefore more tightly
coupled with mobile devices hosting a custom
app to control them. Active wearables (smart
watches and glasses, for example) provide infor-
mation to users and can be used as sources of in-
put to control themselves and the mobile devices
they’re connected to. As a consequence, they can
extend their reach to other devices, which can be
located in their proximity or remotely. Based on
these considerations, we focus exclusively on ac-
tive wearables because they will inevitably drive
interactions with smart objects.

Figure 1 shows the interaction patterns that
we envision between humans using wearable de-
vices and the smart objects that might be around
them. As described, smartphones and wearable
devices are the bridge between the social world
(users), the cyber world (networked hosts), and
the physical world (connected smart objects).

Typically, users might ask these questions when
trying to interact with a smart environment:

1. Which objects are around me?
2. Do I own the right privileges to control or
   interact with these objects directly?
3. What is a given object? What can it do, and
   what can I do with it?
4. How can I interact with it?

To answer these questions and provide a natu-
ral sequence of interactions, we envision an

![Figure 1. Interaction patterns between wearable devices and smart
objects. Smartphones and wearable devices are the bridge between
the social, cyber, and physical worlds.](image-url)
operational flow that can be summarized as follows.

First, the smartphone discovers the smart objects in its proximity (answering Q1) for which the user has been granted the appropriate access privileges (Q2). It uses suitable service discovery (ZeroConf\(^5\) or low-power radio beacon broadcasting) and resource discovery (CoAP Resource Directory) mechanisms, and presents this information on the wearable device interface.

Next, the user can select one item (using vocal input or touch) and get detailed information related to the selected resource, combining the information retrieved in the previous step with other descriptors that can be retrieved on the fly, such as the function set that can be used to interact with the resource\(^6\) or a custom user interface (Q3).

The user can then browse through the available forms of interaction with the selected resource by presenting specialized interfaces for the possible actions that can be performed on the targeted resource (Q4).

The user next interacts with the resources, always using the smartphone as a bridge to perform the actual communication with smart objects, adopting one of the following methods:

- **Get** lets the user retrieve the state associated with the resource by performing a CoAP GET request (for instance, to check the status—closed or open—of a smart-lock-equipped door).
- **Observe** employs an efficient mechanism for receiving asynchronous updates when the state of a resource changes, thus avoiding the need to periodically poll for data (for example, to monitor the temperature of a room so that a thermostat can be activated).\(^7\) This is achieved by performing a CoAP GET request containing an **Observe** option to instruct the object to send updates. An **Observe** relation can then be torn down at any time.
- **Update** acts on a resource to set its state by performing a CoAP POST or PUT request, depending on the function set the resource provides (to switch lights on or off, for example).

The use of CoAP isn’t strictly required: the presence of cross-proxies, which might perform protocol translation, can enable the same interactions with CoAP-unaware clients that might use HTTP.

**Implementation in a Real-World Testbed**

Following the interaction patterns we’ve described, we’ve implemented and tested a wearable-based application for interacting with smart objects in an IoT testbed deployed in our department at the University of Parma.\(^8\) The testbed has 70 IP-addressable devices running CoAP servers that host sensing and actuating resources, and consists of several types of nodes that differ in terms of computational capabilities and radio access interfaces. We can group these nodes into two main classes: 36 constrained IoT nodes and 34 single-board computer (SBC) nodes.

Constrained IoT nodes are class-1 devices\(^9\) based on the Contiki operating system and using IEEE 802.15.4 radio. Specifically, we used six TelosB (www.memsic.com/userfiles/files/Datasheets/WSN/telosb_datasheet.pdf), 20 Zolertia Z1 (http://zolertia.io/z1), and 10 OpenMote CC2538 (www.openmote.com/hardware.html) constrained nodes. SBC nodes are class-2 devices,\(^9\) typically running a Linux operating system and with multiple network interfaces. Specifically, we used the following SBC nodes: 20 Intel Galileo (www.intel.com/content/www/us/en/do-it-yourself/galileo-maker-quark-board.html), five Raspberry Pi Model B (www.raspberrypi.org/products/model-b/), five Arduino Yún (dual Linux/Arduino environment; http://arduino.cc/en/Main/ArduinoYUN), and four UDOO (dual Linux/Arduino environment; http://shop.udoo.org/eu/product/udoo-dual-basic.html) SBC nodes.

The IoT testbed is purposely heterogeneous to simulate expected real-world IoT conditions, characterized by an extremely high degree of smart object diversity. It also highlights how the use of standard communication protocols and mechanisms, combined with our envisioned operational flow, can enforce interoperability and effective interactions among applications in a real WoT fashion.

The mobile/wearable application was developed on the Android Wear platform using LG G Watches and Android Lollipop smartphones. Figure 2 shows the smartwatch screenshots of the running application and how they map to the previously described flow.
There are basically three actors involved in the application’s life cycle: the smartphone, the wearable device, and smart objects; each operation, which can be initiated by any actor, involves an information exchange that affects all actors. In any case, the smartphone is the gateway between smart objects and wearable devices, as Figure 1 shows. The communication between the smartphone and the smart objects occurs using CoAP, based on the Californium library. The smartphone application (SA) communicates with the wearable companion application (WA) using the Android Wearable Data Layer API (http://developer.android.com/training/wearables/datalayer/index.html), which is based on Bluetooth for communication. At startup (step 1 in Figure 2), the SA performs a resource discovery using a combined mechanism: using ZeroConf, it discovers CoAP servers whose resource lists are then retrieved by performing a GET request to the /well-known/core URI; additionally, a multicast GET request to the /well-known/core URI is sent to all smart objects in the network, which return the list of hosted resources.

After the SA has gathered the list of all available resources, it pushes this information to the WA (step 2), which presents the list of resources to the user (view 1). The user selects a resource of interest, which presents a dedicated detail view of the resource (3) that includes resource-specific information, such as its human-readable name and type (view 2). According to the resource’s interface, the WA presents (in a 2D Picker) swipeable cards that contain “action buttons,” which can trigger interactions with the resource using the previously described Get, Observe, and Update schemes (views 3a, 3b, and 3c, respectively). Upon user selection (step 4) (for instance, in Figure 2, a Get interaction is selected), the WA sends a message to the SA (step 5), which then issues the corresponding

Figure 2. Mobile/wearable application for interaction with smart objects. The figure shows the operational flow, indications of communication, and screenshots of the implemented Android application. The smartphone app performs resource discovery (step 1) and pushes the information to the wearable app (2). Once the user chooses a resource, the app presents resource-specific information (3). When the user hits an action button (4), the wearable app sends a message to the smartphone app, which then issues a CoAP request and receives a response from the smart object (6). The smartphone app processes the response and pushes the results to the wearable app (7), which presents it to the user.
CoAP request and receives the response from the smart object (step 6). The response is then processed, and the results are pushed to the WA (step 7) and presented to the user (view 4a). With resource observation (view 3b), when the smart object sends updates to the SA, the SA pushes this information to the WA, which presents a notification (view 4b). A dedicated view is also available that lets users stop observing resources (view 5).

The strong evolutionary trend in several ICT fields, from electronics to telecommunications and computing, has brought significant innovations in how people use and interface with their environment. On one hand, mobile and wearable computing have let people connect anywhere and at any time and consume services while on the go. On the other hand, cheap embedded systems and low-power operating systems and communication protocols have paved the way for the IoT’s development. Although these fields have evolved independently, they’re converging and complementing one another more and more thanks to the flexibility and inherent capabilities of smartphones. The combination and integration between the IoT and mobile and wearable devices is letting industry and researchers envision the path toward a true Internet of Anything \(^1\) that can connect everyone and everything.

Improvements in communication technologies in terms of ever-increasing speed, reliability, and security are enabling the delivery of groundbreaking applications to the general public. While the IoT is being designed around low-power devices with limited capabilities, future 5G networks could bring about enhancements that will foster the development of services and applications that will no longer suffer strong limitations, such as 4K video streaming or real-time remote control. Combined with fog computing techniques \(^2\) aimed at minimizing latency and enabling real-time applications by moving some processing loads to the edge of local networks, the idea of end-to-end communication on the order of milliseconds is going to become a reality. These technologies will lead to the ability to perform haptic interactions with connected things in proximity or remotely, thus determining the rise of the tactile Internet \(^3\) and its application to healthcare, education, robotics, and many other fields. Wearable devices will play a significant role in this mission and are already set to be the drivers and ancestors for many kinds of haptic interactions with things.

Thanks to the IoT, users won’t need to be in charge of monitoring and controlling things when it isn’t needed. However, they will still be able to interact with their surroundings when they want to do so. Natural interaction patterns between users and smart objects through wearable devices will be a key enabler to reach this goal. These models will guide and teach users by increasing their awareness without requiring them to learn new paradigms.

References


Simone Cirani is a postdoctoral research associate at the University of Parma, Italy, where he has also been an adjunct professor in mobile application development and a lecturer on the Internet of Things. His research interests are the Internet of Things, distributed systems, pervasive and mobile computing, and network security. Cirani received his PhD in information technologies from the University of Parma. He is a member of the IEEE Communications Society. Contact him at simone.cirani@unipr.it.

Marco Picone is a postdoctoral research associate at the University of Parma, Italy, an adjunct professor in mobile application development, and a lecturer on the Internet of Things (IoT). His research focuses on mobile and pervasive computing, location-based services, distributed systems, and the IoT. Picone received a PhD in information technologies from the University of Parma. Contact him at marco.picone@unipr.it.

Selected CS articles and columns are available for free at http://ComputingNow.computer.org.