Health Care Applications: A Solution Based on The Internet of Things

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ABSTRACT

This paper proposes the Internet of Things communication framework as the main enabler for distributed worldwide health care applications. Starting from the recent availability of wireless medical sensor prototypes and the growing diffusion of electronic health care record databases, we analyze the requirements of a unified communication framework. Our investigation takes the move by decomposing the storyline of a day in Robert's life, our unlucky character in the not so far future, into simple processes and their interactions. Subsequently, we devise the main communication requirements for those processes and for their integration in the Internet as web services. Finally, we present the Internet of Things protocol stack and the advantages it brings to health care scenarios in terms of the identified requirements.

Categories and Subject Descriptors

J.3 [**Computer Applications**]: Life and Medical Sciences—*Health*; H.4.3 [**Information Systems**]: Applications—*Communications*

General Terms

Design, Management, Standardization

Keywords

Internet of Things, Remote Assistance, System models, Communication protocols

1. INTRODUCTION

The first years of this third millennium saw many changes in people's lifestyle, most of them due to the rise of novel affordable communication technologies. In particular the Internet phenomenon, started in the early nineties of the last century, introduced a whole new paradigm of communication, which has its latest achievement in social networks, such as Facebook, Twitter or Linkedin, just to name a few. At the same time, a new breed of low-cost, low-power communication technologies made it possible for everyday objects to be part of these human-centric networks, thus creating the Internet of Things (IoT) [22, 3].

Electronic health-care solutions have been subject to similar advancements, especially in terms of HealthCare Record (HCR) databases and formats [12] (i.e., Federated HealthCare Record (FHCR) and Electronic HealthCare Record (EHCR) are systematic collections of electronic health information about individual patients or populations) as well as wearable miniaturized sensors [16, 8].

The advent of the Internet of Things and the latest improvements in e-Health pointed towards a fourth paradigm of healthcare information [6]: health data sources can range from body sensor networks to physician analysis and diagnosis and are aggregated into a unified model (FHCR or EHCR) of human health.

Recently, many novel solutions have been proposed to interconnect wearable sensors to the Internet cloud: for instance, a USB connected sensor belt is described in [2] providing electrocardiography (ECG) and respiratory signals, many children care prototypes are introduced in [8], while psychiatric treatment can be enhanced using physiological and environmental readings [4]. For a richer survey on sensors implementation the interested reader is referred to [16].

This paper focuses on how the Internet of Things can be a suitable framework for e-Health communication and especially how low-cost and low-power devices can enhance the quality of life of people suffering from chronic diseases or during emergencies. In addition, we advocate the importance of using open standards based communication solutions for e-Health applications, since allowing heterogeneous hardware and services to seamlessly interact with one another is the cornerstone for removing the operational barriers and creating a holistic health care system on the Internet [19].

In the literature many papers are already pushing for the integration of personal health care networks with the Internet: for instance, reference [3] claims that future *killer applications* of tomorrow's mobile information and communication technologies will include health care practices and infrastructure services provided by clouds, while reference [14] describes a 3-tier telemedicine system consisting of a number of wireless medical sensor nodes (Tier 1), personal server applications running on PDAs and smartphones (Tier 2) and medical service servers distributed in the Internet (Tier 3). In this paper, while proposing an architecture similar to

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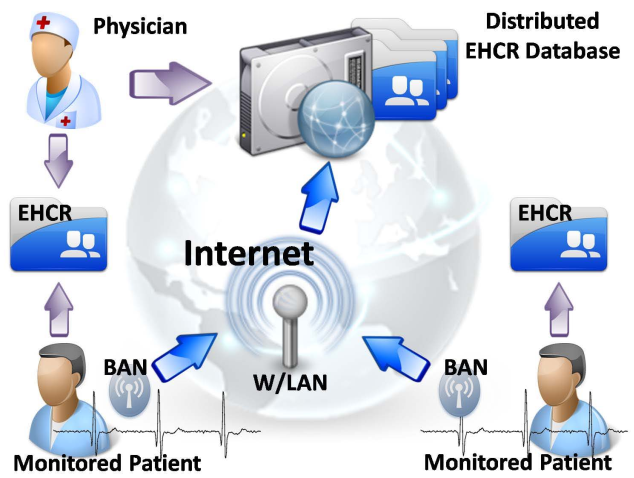

Figure 1: Internet of Things e-Health system model.

those mentioned above, we propose the Internet of Things paradigm as the unifying glue among the plethora of different hardware and software technologies populating the health personal network universe and the Internet.

Fig. 1 shows a graphical representation of our reference model, which will be further detailed in the following sections. The main actors in this model are monitored patients, physicians and distributed information databases. Health relevant information and events are sent via Wireless Body Area Network (WBAN) to the individual HCR in the distributed database through Wireless / Local Area Networks (W/LAN) and the Internet; HCRs can be accessed from anywhere and at anytime by physicians, patients and other users that are allowed to consult them.

The rest of the paper is structured as follows: Section 2 illustrates a futuristic health use case and describes the requirements it implies; Section 3 provides an overview of the system and its processes; Section 4 describes the IoT communication protocols we suggest to adopt for a seamless integration of the health care applications; finally, Section 5 concludes the paper.

2. SCENARIO AND REQUIREMENTS

In order to provide a practical example of how the Internet of Things can be exploited to realize and enhance the remote assistance experience, we will present in the following a few scenes from the futuristic health use case being developed within the EC funded FP7 project IoT-A [1].

Robert, a 55 year old man who suffers from diabetes, has got a wireless identifiable device (iDiab[1]) implanted that steadily measures his blood sugar and tells him when it is about to reach a critical status. This device is part of a body sensor system (hCheck) that continuously monitors Robert's general health conditions by measuring vital parameters, such as the heart beat rate and the breathing rate.

Last night Robert organized a party and this morning, disobeying his doctor's prescriptions, decides to eat a slice of cake for breakfast. A few minutes later, while Robert's is brushing his teeth, the blood sugar starts increasing and it is possibly going beyond the normal threshold within moments. The iDiab recognizes the status and sends a message to his zPhone, a smart phone equipped with built-in IoT-communicators that allow it to communicate with any wireless network interface. The zPhone sets up an immediate alarm and a pleasant voice starts to talk to him, reminding him to inject himself insulin within the next 30 minutes. Robert is once again pleased to have these little smart things in and around him that help him alleviate the problems related to his condition.

After Robert has injected the insulin as suggested, he leaves home and goes to work. During the morning he gets an unexpected incoming call from his personal doctor at the hospital. He tells Robert that he is a bit worried about his mid-term blood sugar development as he has just checked Robert's HCR for blood sugar levels. It does not seem to be too serious, but he prefers to set up an appointment for the following week.

While coming back to his office after lunch, Robert slips on the stairway, falls and hits the ground hurting his leg. The accelerometers of his zPhone instantly recognize that something dangerous may have happened and query the hCheck sensors about Robert's condition. The two devices agree that Robert may be in danger and the zPhone releases an emergency message sending the location data of where he fell as well as his personal ID to the emergency centre.

Using state-of-the-art IoT communication the nearest emergency centre is alerted and asked to send an ambulance to Robert immediately. On the way, the physician connects to Robert's hCheck system and verifies that, although something painful must have happened, he is not in immediate danger since there is no bleeding and he is conscious. A few minutes after Robert fell, the physician steps into the corridor and starts with the first aid.

Just after the ambulance arrived at the hospital, Robert is promptly identified and all the necessary medical data is made available by Robert's HCR, which makes it easy to prepare all helpful information for the doctor beforehand. After having performed the needed X-ray scan, the physicians can confirm that Robert's leg is broken and can readily start the usual procedure: once again IoT technologies allowed physicians to save much time and to prevent Robert's conditions from getting worse.

Although very ill-fated, Robert's day highlights the importance of a homogeneous, efficient communication framework as the one provided by the Internet of Things. In particular, the following requirements emerge from the scenario:

- *Interoperability* is needed to enable things as different as the iDiab, the hCheck and the zPhone to cooperate so as to provide the desired service.
- *Bounded latency and reliability* need to be granted when dealing with emergency situations in order for the intervention to be effective.
- *Privacy, authentication and integrity* are mandatory when sensitive data such as HCR are exchanged across the network.

In the following, these requirements will be used to devise system functionalities and processes (Section 3) and communication protocols (Section 4) to support the use of IoT technologies for health care applications.

[1]All the device names used here and in the following are fictitious and are used for easy reference only; however, prototypes are already available for many of them as mentioned in Section 1.

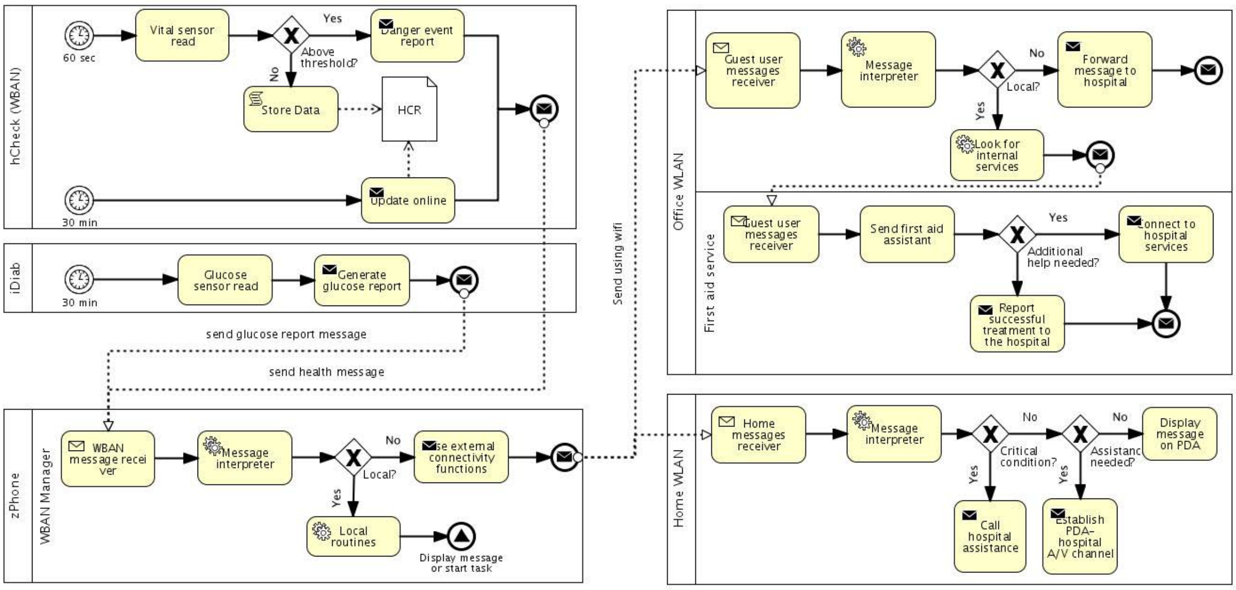

Figure 2: Internet of Things e-Health process model.

3. SYSTEM AND PROCESSES

We start by introducing a first classification, in order to understand the need for a unifying framework such as the IoT: devices used in health care applications belong either to constrained (see the datasheet in [9] for a typical constrained platform) or unconstrained networks. The differences between the two concern the hardware capabilities: in the former category devices are limited by low energy availability, since they are often battery powered, bandwidth as low as 250 kb/s and computational power as low as few MHz; in the latter category such limitations do not exist and, in order to provide the better services, applications exploit all the hardware capabilities offered. With reference to Robert's scenario, the iDiab and the hCheck devices belong to the constrained category while the zPhone and the network infrastructure devices belong to the unconstrained part.

Fig. 2 shows a Business Process Model Notation (BPMN) [21] diagram of the scenario presented in Section 2. Robert's devices are drawn on the left-hand side of the picture as separate task pools, while the different networks they interact with are placed on the right-hand side. This diagram provides a simplified representation of the processes running during Robert's day.

The hCheck system shows two processes related to Robert's vital parameters, one that checks the sensor readings once a minute, the other that updates Robert's HCR twice an hour, respectively. Also, the hCheck provides asynchronous event notification when any given vital parameter is reported to show anomalous trends. This is made possible thanks to advanced pattern recognition and prediction techniques that compute Robert's normal conditions and detect when something wrong is happening. Similarly, the iDiab device checks the blood glucose level twice an hour and updates Robert's HCR accordingly.

Both hCheck and iDiab can seamless interact with the HCR database exploiting the gateway functionalities offered by the zPhone; in fact, this unconstrained device provides the needed tools to make the compressed messages sent by the constrained devices understandable by the other unconstrained networks. In particular, thanks to IoT communication protocols, it is possible to compress a message as big as 1 kilobyte into a few tens of bytes while maintaining all the desired capabilities of a full-blown IP network [22].

Moreover, exploiting IoT solutions makes it possible to differentiate messages by priorities and categories so that urgent emergency notifications can be managed within a bounded time, while periodic updates are dispatched using energy expenditure-minimizing paths. A further benefit of using IP capable technologies is the ease of compatibility with existing infrastructures: for instance, in Robert's use case the hCheck messages could have also exploited Robert's home gateway to connect to the Internet instead of passing through the zPhone. Finally, it does not matter who the hardware provider is, since IoT communications leverage on open standards, which are both accessible and designed for Internet integration.

As a last remark, IoT solutions make it possible to realize any functionality or application as a lightweight standard web service. This provides many benefits, but here we will list only a few related to health care applications: *i*) any single device can be addressed separately and accessed from anywhere in the Web; *ii*) all the interactions happen as among browsers and websites; *iii*) any given service description can be fetched when needed, so that users do not need specific applications for any given device.

4. COMMUNICATIONS

This section describes how IoT communication standards satisfy the requirements of health care applications and provides an overview of the suggested protocols, their functionalities and their mapping to the standard Internet protocol stack. For more technical details and performance evaluation the interested reader is referred to [5, 7], while a qualita-

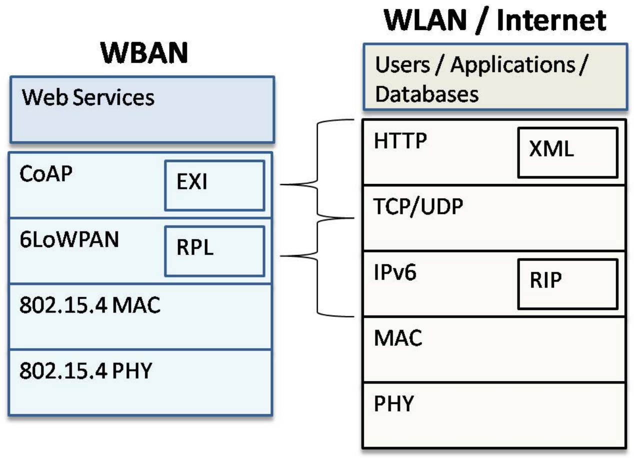

Figure 3: Internet of Things protocol stack and its mapping to Internet protocols.

tive description of the IoT protocol stack is in the following. Fig. 3 shows the IoT stack and its Internet mapping at a glance.

The core of IoT solutions is *IPv6 over Low power Wireless Personal Area Networks* (6LoWPAN) [15] which is proposed by the IETF to provide Internet connectivity to constrained WPAN devices through IPv6. 6LoWPAN defines message frame formats, fragmentation methods and header compression techniques required to fit IPv6/UDP datagrams in the very limited IEEE 802.15.4 frame size. The 6LoWPAN innovations provide IP access to a wide set of networked devices, which, being low-cost, low-power constrained hosts, could not easily benefit from the huge addressing space of IPv6.

6LoWPAN is able to reduce the IPv6/UDP header while maintaining the main functionalities and the size of the addressing space, thanks to a cross-layer optimization approach. This is achieved by inferring parts of the IP headers from the MAC header, thus an IPv6 40-byte header can be shrunk into a single-byte HC1 header, while the UDP header size can be similarly reduced. The 6LoWPAN format is supported by many standardization bodies, including ETSI, IPSO and the ZigBee alliance.

Routing functionalities are provided by the *Routing Protocol for Low power and lossy networks* (RPL) [20], which is another IETF solution discussed in the Routing Over Low power and Lossy networks (ROLL) working group. RPL supports different routing path optimizations based on specific objective functions: for instance, high priority packets can be routed to offer low delivery delay, while delay tolerant traffic can be handled to minimize the energy expenditure or to maximize the network capacity.

Another important feature of RPL is its intrinsic scalability with respect to the network density: in fact, it adopts a message suppression mechanism, called Trickle, which is triggered upon the detection of a tuneable number of messages. In addition, RPL is used for performing lightweight address resolution during network setup and in case of network topology changes.

The *Constrained Application Protocol* (CoAP) [18] completes the main part of the IoT communication solution. CoAP has been drafted by the Constrained RESTful Environments (CoRE) working group of IETF and is based on the REpresentational State Transfer (REST) [11] paradigm. According to this paradigm, any data exchange is performed using basic HTTP protocol methods such as GET, POST, DELETE and UPDATE.

CoAP specification is aimed at a web-oriented binary protocol, designed for constrained devices, allowing for a seamless mapping to HTTP. Enabling HTTP communications in constrained environments means to make sensing and actuation services easily retrievable, like any other information source in the Internet. Like 6LoWPAN, CoAP is designed to fit in the smallest frames; in fact an HTTP request with a size on the order of some tens of bytes can be mapped into a CoAP request of as few as 4 bytes, while maintaining all the functionalities.

Finally, IoT exploits the *Efficient XML Interchange* (EXI) [17] format to mitigate the size and parsing complexity of the eXtensible Markup Language (XML) while maintaining most of its capability of enhancing data with context information in order to be able to understand them regardless of how they are generated. EXI has been proposed by the W3C consortium and exploits the XML document structure to perform a dictionary based compression. EXI can save up to 90% of the original XML messages size, thus carrying a rich set of information in very small packets.

Thanks to the compact yet versatile design of this protocol stack, it is possible to realize simple and efficient web services that can be used on constrained devices. The key factors to achieve this are the HTTP/IP compliant communications and the capability of managing XML documents. This makes it possible to design applications and services which can be exploited by standard browsers and other web applications without any translation in between. Also, information provided by the embedded device can be used by any non-specifically designed application, since our solution is able to characterize any piece of information of context specific descriptors. Moreover, providing data, functionalities and services as web services allows for a complete horizontalization of the offered solutions, since they can be used *as is* in any modern IT system.

IoT is not the only attempt to provide a unified communication framework for health care and other distributed networked applications. Many custom solutions [16] have been recently provided in the literature and other efforts have been made to implement standard Internet protocols as they are on constrained devices. Also, many middleware solutions trying to be comprehensive [12, 10] have been proposed. Although all of these proposals have their own distinctive merits, to us they are not able to fully satisfy all the mentioned requirements: custom solutions will never provide the necessary interoperability level, while using standards without constrained device optimization will lead to unavoidable performance degradation, and finally midlleware solutions being usually very application specific may not offer the needed flexibility.

5. CONCLUSIONS

In this paper, we described how the Internet of Things can be the main enabler for distributed health care applications and, conversely, how health care is one of the most promising *killer applications* for the IoT.

We provided a description of the impact of the proposed framework on a particularly ill-fated day in the life of Robert, our futuristic technology-friendly character. Though not yet completely available, the components presented in the use case are at different stages of realization [16]; also, further studies [13] proved that people's acceptance of IoT technologies is wide and increasing.

Subsequently, we analyzed our storyline with a BPMN model, highlighting devices, networks and processes. This analysis allowed us to extract the needed requirements on the communication system, which we further used to validate the IoT protocol stack.

In particular, we described each of the protocols proposed by the main standardization bodies for implementing the IoT and for each of them we explained how they contribute to satisfy health care application requirements.

Currently, we are contributing to the realization of an actual implementation of a comprehensive health care system within the IoT-A project [1]. Finally, further work will be devoted to the integration of runtime sensing information into health care records.

6. ACKNOWLEDGMENTS

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