Internet of Things in Healthcare Applications

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Abstract – **Internet of Things (IoT) is a pervasive technology which covers a number of application domains. The paper presents a survey on telemedicine standards and a study on applicability of IoT Reference Domain Model in the area of healthcare. The IoT Reverence Domain Model introduces the main concepts of IoT and the relations between these concepts. As far as the abstraction level describes the concepts in a way which is independent of specific application area, it is important to investigate potential application scenarios and use cases. The paper presents the main abstraction and relationships and discusses their implementation analyzing existing solutions in healthcare applications. An enhancement of the IoT Reference Domain Model is suggested.**

Keywords – **Internet of Thing, e-health, architectural domain model, device-to-device communications.**

I. Introduction

Development of Internet is a continuous process and one of the next steps is the evolution from network of networks composed of interconnected computers to interconnected objects which result in Internet of Things (IoT) [1], [2]. The objects posses own Internet protocol (IP) addresses. They can be embedded in complicated systems and use sensors to receive information from their environment [3]. The objects recognize each other and become more intelligent exchanging data gathered from other objects. The IoT applications are expected to contribute to solving challenges in aging society, vehicle telematics and transport logistics, agricultural monitoring, environment prevention and so on. [4], [5], [6], [7], [8]. It is envisaged that this interconnection between physical objects will have significant impact in the area of healthcare [9].

There are three main organizations that create standards related to Electronic Health Records- CEN TC 251, HL7 and ASTM E31[10]. An important area of CEN/TC 251 work are standards for the Electronic Healthcare Record [11]. These include a record architecture establishing the principles for representing the information content and record structure, a set of concepts and terms for record components, and rules and mechanisms for sharing and exchanging records. A domain model representing a formal description of the context within which the healthcare records are used, is established to document requirements for these standards. The standards are aimed at the semantic organization of information and knowledge so as to make it of practical use in the domains of health informatics and telematics, and the provision of information and criteria to support harmonization. This encompasses clinical, managerial and operational aspects of the medical record and enabling access to other knowledge. Further the activities are focused at providing a statutory framework to ensure that information systems used in healthcare have appropriate levels of quality, safety and security.

ASTM (American Society for Testing and Materials) develops standards related to the architecture, content, storage, security, confidentiality, functionality, and communication of information used within healthcare and healthcare decision making, including patient-specific information and knowledge [12].

Health Level Seven (HL7) is involved in producing standards for a particular healthcare domain such as pharmacy, medical devices, imaging or insurance (claims processing) transactions [13]. The name refers to the application level of the Open Systems Interconnection (OSI). Standards address definition of the data to be exchanged, the timing of the interchange, and the communication of certain errors to the application. The seventh level supports such functions as security checks, participant identification, availability checks, exchange mechanism negotiations and, most importantly, data exchange structuring.

Healthcare is an information-intensive and a communication-intensive business. The volume of information exchanged between departments within hospitals and between primary and secondary care providers is large. EDI stands for Electronic Data Interchange. EDI is the interchange of standard formatted data between the computer application systems of trading partners with minimal manual intervention [14], [15]. EDI standard, consists of a grammar (syntax and rules for structuring the data) and a vocabulary (contained in the directories of data elements, composite data elements, segments, and messages).

The IoT Architectural Reference Model provides interoperability solutions at communication and service levels across various platforms [16], [17]. It reflects the requirements of different stakeholders groups and adopts established working solutions of various aspects of the IoT. The foundation of the Reference Architectural Model is the Domain Model that introduces the main concepts of Internet of Things and the relations between these concepts. The abstraction level describes the concepts in a way which is independent of specific application area. The aim of the paper is to outline potential application scenarios of IoT Domain Model and use cases in the area of telemedicine.

The paper is structured as follows. In Section II, the main Domain Model abstractions and relationships are presented and their implementation in healthcare applications is discussed. Section III describes the suggested enhancement of the IoT Reference Domain Model that reflects the device-to-device communications in a network. A new abstract concept and its relationships are added. Section IV illustrates the application of the concept in healthcare area. Finally the conclusion summarizes the contribution.

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II. Mapping of IoT Reference Domain Model onto Healthcare Applications

The IoT Reference Domain Model provides a description of greater abstraction than that, what is inherent to real systems and applications. It describes concepts belonging to IoT area defining basic attributes of objects, their responsibilities and relationships between objects as shown in Fig.1.

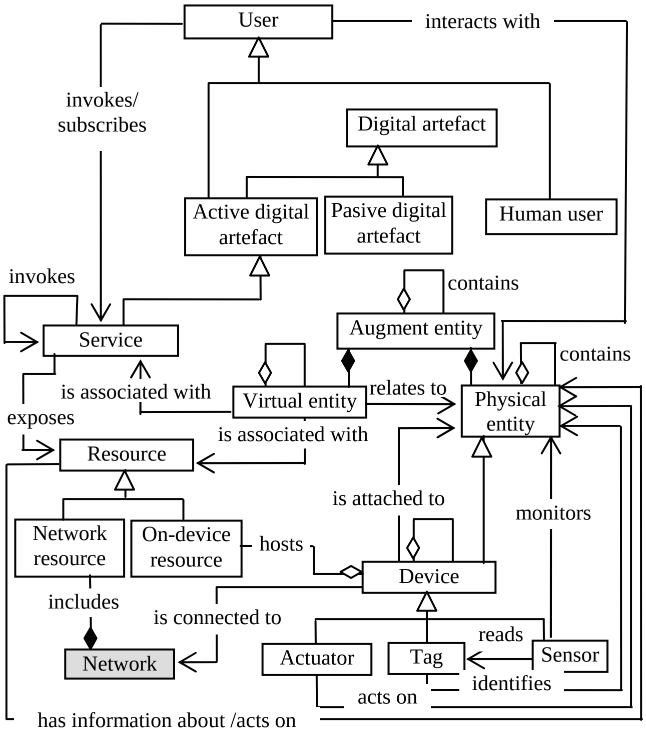

Fig.1 IoT Domain model [16]
(the suggested enhancement is shown in grey)

The *User* is a human or a software program acting according business logic that is interested in interacting with a particular physical object. *Users* across healthcare spectrum include healthcare professionals (physicians, nurses, dentists), healthcare provider organisations (hospital, clinics, nursing homes, rehabilitation centres), support service providers (pharmacies, diagnostic centres, blood banks, laboratories), idividuals, employers, payers (insurance firms, 3rd party administrators, brokers) and relevant software applications.

The user interacts with a *Physical Entity*. The *Physical Entity* is any physical object that is relevant from a user or application perspective. In the area of healthcare, *Physical Entity* is the patient.

Virtual Entity is the Physical entity's digital representation. Digital representation of a patient can be 3D models, database entries, instances of a class in an object-oriented technology, and a social network account also. *Virtual Entities* are *Digital Artefacts* that can be classified as either active or passive. *Active Digital Artifacts* are running software applications, agents or *Services* that can access other *Services* or *Resources*. For example, an *Active Digital Artefact* can be an application that monitors the blood pressure of the patient and sends a message to the healthcare professional in case of emergency, or videoconference application enabling doctors to be digitally connected through mobile communications and to develop therapies in cooperation with other doctors and liaise closely with patients. *Passive digital artefacts* are passive software entries such as database entries with vital signs measurements or other digital representations of the *Physical entity*.

Things in the IoT are represented as *Augment entity* which is composed of one *Virtual Entity* and the associated *Physical entity*. The technological interface for interacting with or gaining information about the *Physical entity* is the *Device* or *Devices*. *Devices* are usually embedded into, attached to or placed closed to the *Physical Entity*. A *Device* is a mediator between *Physical* and *Virtual Entities*. Clinical devices are instruments used to assess the human condition and to deliver medical treatment.

Medical technology has benefited greatly by incorporating rapid advances in the science of information technology into many measurements and devices. But often this has been done in an unstructured manner with many devices being developed in an isolated way that makes impossible both communication between them and with hospital data management systems. As the advantages of such communication became more and more obvious, a pressing need for technical standardisation and new protocols resulted in the creation of some standardisation activities. Great efforts were mainly held by the IEEE 1073, VITAL and the Point of Care Connectivity Industry Consortium to enable communication to exist in an easy and open way, with subsequent clinical, administrative and research benefits. Using a complete data-transfer protocols such as RS-232, RS-422, or RS-485, or using wireless protocols such as Bluetooth, new functionality can be built into medical devices. That enables them in many cases to upload some of the manual tasks to the server. Traditional patient charts are replaced by the data delivered to a central processing station. These data are then analyzed and time-stamped by a knowledge-based engine and delivered to a nursing station in real time, along with an at-a-glance summary. Such a system eliminates delays between the gathering and the delivery of the information to the clinician. The systems are also designed to prevent manipulation of the database, ensuring the validity of the data. Examples of medical *Devices* include spirometers, capnographs, weight and fat scales, pulse oximeters, clucometers, heart rate monitors, electrocardiograms, holters, echocardiographs, thermometers, multiparameter devices etc. [18]. Specially designed for telemedicine and home care applications, some devices transmit the data wirelessly to a gateway, which then forwards this information via internet to a telemedicine call centre or a secure data repository.

Regarding healthcare area, there exist some assumptions based on the limited capabilities of devices within low power wireless personal networks. While some devices are expected to be extremely limited (reduced function devices), more capable full function devices will also be present, albeit in much smaller numbers. The full function devices typically have more resources and may be mains powered. Accordingly, they aid reduced function devices by providing functions such as network coordination, packet forwarding, interfacing with other types of networks, etc.

From an IoT point of view the following three types of *Devices* are of interest. *Sensors* provide information about the physical state of the Physical entity. Information from *Sensors* can be recorded for later retrieval. *Sensors* assist patients with home diagnostics for chronic illnesses and help them with prevention or to make lifestyle changes advised by medical professionals. Blood pressure, weight or blood sugar - handy measuring sensors ensure that the most important vital data might be always to hand, even when on the move [19]. *Sensors* transfer the relevant data to the patient's cell phone or smartphone e.g. by Bluetooth. From there it is transferred to his or her personal online diary. The patient can also add information such as medications, mealtimes, sporting activities or visits to the doctor, to this diary via a web portal or while on the move.

Tags are used to identify *Physical Entities* to which they are usually attached to. The identification process can be optical (barcodes or QR code) or it can be radio frequency based (RFID) [20], [21].

Actuators are special *Devices* that can modify the physical state of one or more *Physical Entities*. An example of *Actuator* is defibrillator which is designed to pass electrical current through a patient's heart and to restore a patient's heart rhythm to normal.

Resources are heterogeneous, system specific software components that store or process data or information about one or more *Physical Entities*, or that provide access to measurements and actuations in case of *Sensors* and *Actuators* respectively. Two types of resources can be distinguished. *On Device Resources* are hosted on *Devices* and are regarded as software deployed locally on the *Device*. *Network Resources* are resources available in the network. *Network Resources* run on a dedicated server in the network or in the 'cloud'.

A *Service* provides a well-defined and standardized interface offering all necessary functionalities for interacting with *Physical Entities* and related processes. An important issue related to *Service* is service orchestration both for IoT *Service* and non-IoT *Service* [22]. Service platform independency can be achieved, for example by using Web Services technology [23]. In the area of healthcare, *Services* are aimed at people that require nursing care or incur certain medical risks such as slip and fall accidents and provide location information in case of injury for family members and emergency services.

III. Enhancement of the IoT Domain Model

The concept that is suggested to be included in the IoT Domain reference model is *Network*. Devices can be connected in a low power personal area *Network*. The main requirement to this type of *Network* is to provide IP connectivity. The requirement for IP connectivity is driven by the following: The many connected devices make network auto configuration and statelessness highly desirable and for this, IPv6 has ready solutions; The large number of devices poses the need for a large address space, well met by IPv6; Given the limited packet size, the IPv6 address format allows subsuming of IEEE 802.15.4 addresses if so desired; Simple interconnectivity to other IP networks including the Internet.

The network must support various topologies including mesh and star. Mesh topologies imply multi-hop routing, to a desired destination. In this case, intermediate devices act as packet forwarders at the link layer (akin to routers at the network layer). Typically these are full function devices that have more capabilities in terms of power, computation, etc. The requirements on the routing protocol are formulated in [24], [25] and include the following:

- The routing protocol must impose low (or no) overhead on data packets independently of the number of hops.
- The routing protocols should have low routing overhead balanced with topology changes and power conservation.
- The computation and memory requirements in the routing protocol should be minimal to satisfy the low cost and low power objectives. Thus, storage and maintenance of large routing tables is detrimental.
- Support for network topologies in which devices may be battery or mains-powered. This implies the appropriate considerations for routing in the presence of sleeping nodes.

As with mesh topologies, star topologies include provisioning a subset of *Devices* with packet forwarding functionality. If, in addition to IEEE 802.15.4, these *Devices* use other kinds of network interfaces such as Ethernet or IEEE 802.11, the goal is to seamlessly integrate the *Networks* built over those different technologies.

IV. Use case

The sketched use case presents healthcare at home by remote assistance. Data is collected on periodic base and upon occurrence of events. In healthcare applications, delays or loss of information may be a matter of life or death, so data transmission must be real time and reliable. The patient's network is of small size with high density of nodes powered by hybrid sources. The devices are always on. They are connected in a patient's body network in star topology and controlled by a local controller dealing with data aggregation and dynamic network attachment when the patient moves around at home. Some devices can be installed with mains powered status. There may be multipath interference due to walls and obstacles. The communication between patient's network nodes is limited to a home environment. The traffic pattern for data collection is point-to-multipoint or multipoint-to-point and for local diagnostics it is point-to-point. An example scenario is shown in Fig.2.

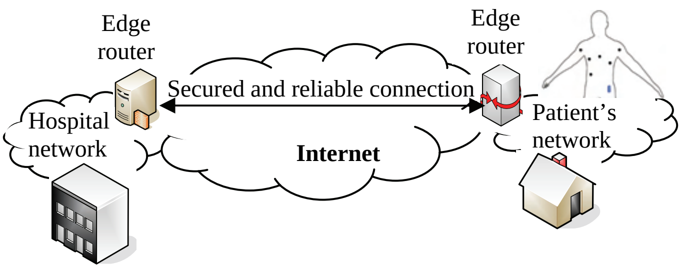

Fig.2 An example healthcare scenario

Being at home or visiting the connected hospital the patient, whose sensed information is of interest, must be identifiable uniquely. When the patient's network is configured to use unique global IPv6 address, then it is possible to identify the patient by the very same address. Unfortunately issues regarding privacy and security must be considered. Moreover, an obligatory identification system featuring string authority and authentication must be deployed at the hospital network where the patient's information is transferred to. The high level of data privacy imposes a reliable and secure connection between the hospital edge router and the patient's edge router. This implies an additional security policy between two networks.

V. CONCLUSION

The paper studies the applicability of the IoT reference domain model to healthcare applications. The main abstract concepts and their relationships are mapped onto healthcare views and perspectives. An enhancement of the IoT reference domain model is suggested and discussed. The new concept representing the device interworking in an IP based network with its relationships is introduced. An use case scenario with inherent characteristics is investigated.

ACKNOWLEDGEMENT

The work is conducted under the grant of the Project 122pd0007-07 funded by Research and Development Sector, TU-Sofia, Bulgaria.

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