Trends in Entertainment, Home Automation and e-Health: Toward Cross-Domain Integration

Antonio Aragüés, Ignacio Martínez, Pilar del Valle, Pilar Muñoz, Javier Escayola, and Jesús D. Trigo,
University Zaragoza (UZ)

ABSTRACT

Recent advances in consumer networking and emerging technologies are promoting a paradigm shift in the way environments such as entertainment, home automation or e-Health are traditionally understood. However, available technologies present different characteristics depending on the environment or the working domain that, in a context of non-experienced users, hinders the development of interoperable services. This article compares the most recent technological proposals and analyzes their key points, and presents a compilation of the major interoperability proposals and initiatives for the considered communication domains. The work is completed with a reasoned discussion on trends on architectural approaches to cross-domain integration that can be used to overcome the issues generated by the segmented ecosystems presented above.

INTRODUCTION

Recent advances in consumer networking and emerging technologies are promoting a paradigm shift in the way environments such as entertainment, home automation, or e-Health are traditionally understood. The latest products in consumer electronics — such as smartphones, tablets, smart televisions, medical devices, etc. — are empowering users to custom shape a smart home, in which their spare time, domotics, or health can be intelligently managed. Such environments have different technological requirements, depending on their specific features: the entertainment domain requires high bandwidth, streaming capabilities, real time and low latency; the home automation domain requires low-power and small sensors; and the e-Health domain requires high security, univocal measure-patient match and ubiquitous capabilities. Cross-domain solutions are being applied in unconventional ways to provide novel platforms where interoperation between heterogeneous technologies begins to be possible.

The field of communications has witnessed the simultaneous spread of numerous general-purpose, low-power, and close-proximity technologies, such as Wi-Fi, WUSB, Bluetooth, ZigBee, or NFC, to name only a few. Such technologies are crucial in the development of new consumer services. However, despite their success, the wireless communication technologies arena is a convoluted and segmented ecosystem (Fig. 1). The available technologies present different characteristics depending on the environment or the working domain. In a context of non-experienced users, such heterogeneity hinders the development of interoperable services [1].

In an attempt to seamlessly handle this heterogeneity in the aforementioned domains, several higher-layer interoperability protocol stacks and services have emerged, such as DLNA for entertainment, several ZigBee profiles for home automation, or different interoperability standards for e-Health [2]. However, these efforts lack cross-domain initiatives that enable integration of the above-mentioned consumer domains in order to build the longed-for smart home.

To achieve such a goal therefore required the design of novel abstraction-based architectures that facilitate the path toward the integration of different scenarios in a single framework. Some proposals — based on different approaches — can be found in the literature [3]-[8]. The two prevailing styles for distributed systems include: Service Oriented Architectures (SOA) and Resource Oriented Architectures (ROA) that, at the same time, make use of other closely-related concepts such as "Web of Things," Web Services (WS), or Physical Mashups. An appropriate combination of technologies and interoperability initiatives as well as the selection of a suitable architecture is required if a full fledged, smart home that enables cross-domain integration aims to be achieved.

The objectives of this article are:
- To review and compare the main consumer communication technologies that can be applied in home environments such as entertainment, home automation or e-Health.

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- To present a sorted compilation of the major interoperability proposals and initiatives for the aforementioned domains.
- To perform a reasoned discussion on trends on architectural approaches for cross-domain integration that can be used to overcome the issues generated by the segmented ecosystems presented above.

The conclusions are then drawn.

Emerging Wireless Technologies for Consumer Networking

This section compares the most recent emerging wireless technologies for consumer networking, analyzing their key points. Technologies can be categorized based on several aspects. The proposed review distinguishes two main groups: the most spread technologies (subdivided according to their main features into general-purpose, close-proximity, and low-power) and particular initiatives for each one of the communications environments previously introduced: entertainment, home automation and e-health. It is worth noting that the technologies included in the first group could be applied to any of the environments of the second group. For every technology, an extended technological study can be found in [2] and the technical information within the recommended scenarios are shown in Fig. 1 and detailed in Table 1.

The first group comprises general-purpose (i.e., not designed for a specific domain) technologies such as Wi-Fi, Bluetooth, ZigBee, and WUSB. The IEEE 802.11 family of standards, commercialized under the Wi-Fi trademark, has evolved through different versions, 802.11a/b/g/n, to the most recent 802.11ac, currently under development, which enables multi-station WLAN by using wider radio bandwidth, up to eight streams and high-density modulation. Bluetooth has also released several versions, such as BT2.1+EDR, BT3.0+HS, and the most recent BT4.0 or BTLE available in some high-end smartphones and featuring ultra-low-power consumption idle operation mode (several times less than conventional Bluetooth devices), low latency, simple device discovery service and faster transfer speeds. Bluetooth and Wi-Fi have some similar applications as they are considered the replacement for cabling: Bluetooth for portable equipment and Wi-Fi for general WLAN (high-power consumption). ZigBee, operating on the IEEE 802.15.4 radio standard, is focused on embedded applications requiring low data rates, low-power consumption and a considerably simpler and cheaper hardware than Bluetooth (battery life lasts 30 times longer). WUSB is a short-range and high-bandwidth wireless protocol — based on the emerging UWB radio technology — that features extensive bandwidth, improved power efficiency, proximity-based association mechanism and wired-like security.

The second group, which includes some of the previous options, covers low-power technologies such as ANT, Z-Wave, DASH7, and 6LoWPAN. ANT is a proprietary ultra-low-power technology that features simple design, low latency, high resource optimization, network flexibility and scalability, ease of use with low-cost systems, very high transfer rate (e.g. ANT stays on air four times less than ZigBee to transmit a given volume of data) and optimized battery life (e.g., with a consumption of 24 hours/day and seven days/week, ANT works up to three years, ZigBee up to six months and Bluetooth up to seven days). Z-Wave is a proprietary protocol based on low-power consumption RF embedded technology with highly optimized headers for reliable and low-latency communication of small data packets, unlike Wi-Fi systems that are designed primarily for high-bandwidth data flow. DASH7, based on ISO/IEC 18000-7 and re-oriented from military purposes to commercial applications as an alternative to proprietary protocols like ZigBee or Z-Wave, features ultra-low-power consumption (10 times less than ZigBee), high coverage ranges (six times more than ZigBee) and multi-year battery life, low latency in object location, encryption and reduced protocol stack. 6LoWPAN, defined by IETF and oriented toward embedded devices, features Internet Protocol (IP) connectivity with a simple header frame design and a hierarchical addressing model that, similar to DASH7 and unlike ZigBee, guarantees the interoperability among IP-based devices that enables building the wireless "Web of Things," as will be discussed later.

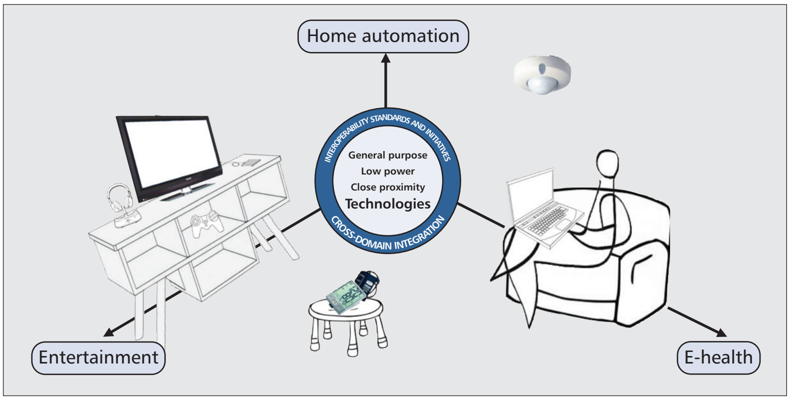

Figure 1. *Scheme of wireless communication technologies arena for consumer networking at home.*

The third group consists of close-proximity technologies such as NFC and TransferJet. NFC, based on RF identification (RFID) standards including ISO/IEC18092 and ECMA340, features fast data transfer with reduced payload, quick connection set-up (about 1s) and low coverage (can work up till a few centimeters) as it uses magnetic fields as media. TransferJet is a new close-proximity wireless technology featuring simple operation by just approaching two devices, such as automatically initiating a P2P content transfer, that allows, as with NFC, high-speed data exchange. However, TransferJet is intended to replace USB cables for massive file transfer at super-fast speeds, while NFC is intended to securely send and receive small-data transactions.

The fourth group is focused on specific technologies for entertainment (such as WHDI,

		General Purpose				Low-Power				Close-prox.		Entertain-ment			Home Automation					e-Health	
		Wi-Fi	Bluetooth	ZigBee	WUSB	ANT	Z-Wave	DASH7	6LowPAN	NFC	TransferJet	WHDI	WiHD	WiGig	LonWorks	RuBee	X10	KNX	EnOcean	Sensium	Zarlink
Scenarios	Telecommunication devices (routers)	•																			
	High-definition multimedia solutions											•	•	•							
	Remote control for home automation			•		•	•								•	•	•	•	•		
	Connectivity of medical devices		•	•	•															•	•
	Wireless Sensor Networks (WSN)			•		•	•	•	•						•	•			•		•
	Embedded systems			•		•	•	•	•	•	•				•				•		•
	Smart-energy based systems		•	•		•	•	•	•							•			•	•	•
	IP-connectivity supported solutions	•						•	•						•						
Topology	Point-to-Point (P2P)	•		•	•	•				•	•	•	•	•							•
	Mesh					•	•	•	•						•	•	•	•	•		
	Star (master-slave)		•	•																•	
Cover range	Several centimeters									•	•										
	Several meters				•	•	•					•	•	•		•				•	•
	Up to 100m	•	•	•					•								•				
	More than 100m														•			•	•		
Maximum data rate	Several b/s																•				
	Several kb/s						•									•				•	
	Up to 250kb/s			•				•	•										•		•
	Several Mb/s		•			•									•			•			
	Up to 450Mb/s				•					•	•										
	More than 1Gb/s	•										•	•	•							
Power	Ultra-low-power consumption		•			•		•								•			•		•
	Low-power consumption		•	•			•		•	•	•									•	
	Standard power consumption	•	•		•							•	•	•	•		•	•			
RF band	120–130kHz																				
	13.56MHz									•											
	433MHz							•													•
	868–915MHz			•			•		•									•	•	•	
	2.4GHz		•	•		•			•												
	More than 2.4GHz	•			•						•	•	•	•	•						
Entities, bodies	Alliance, Special Interest Group (SIG)	•	•	•	•		•	•			•	•	•	•				•	•		
	Standard (IEEE, ISO, IETF)	•		•				•	•	•						•		•			
	Proprietary					•									•		•			•	•

Table 1. *Comparative study of proposed emerging technologies for entertainment, home automation and e-Health.*

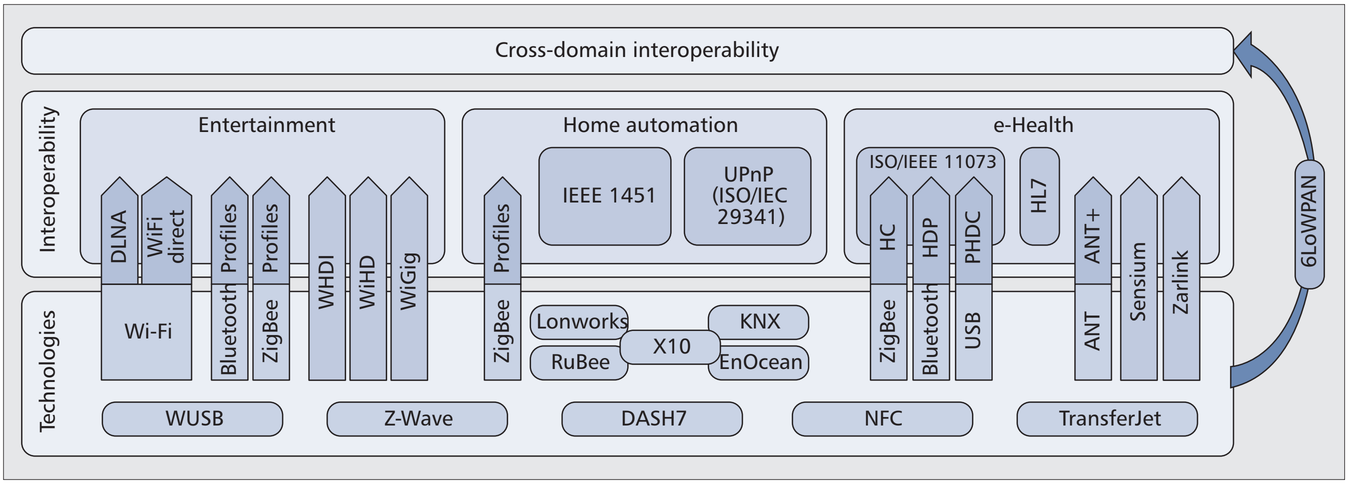

Figure 2. *Conceptual scheme of cross-domain integration for consumer electronics, home automation and e-Health.*

WiHD and WiGig), home automation (such as LonWorks, RuBee, X10, KNX and EnOcean) and e-Health (such as Sensium and Zarlink). LonWorks is a proprietary networking platform over ISO/IEC 14908-1 that addresses control of home applications over several media such as RF and twisted pair, power-lines or fiber optics. RuBee, supported by IEEE 1902.1, defines the air interface for radiating transceiver radio tags, using long wavelength signals and very-low-power consumption devices, and fills a gap between non-network-based RFID standards and existing high-bandwidth network standards such as IEEE 802.11 and IEEE 802.15.4. X10 is an international and open industry standard for electronic device communication that uses power-line wiring for signaling and handling control, where the signals involve short RF bursts representing digital information, and defines a wireless radio protocol. KNX, developed by EN 50090 and ISO/IEC 14543, is an OSI-based network protocol for intelligent buildings that groups three previous standards leveraging the EIB communication stack with extended physical layers, configuration modes and the application experience of BatiBUS and EHS. EnOcean is a German wireless technology based on the concepts of energy harvesting, energetically efficient exploitation of applied slight mechanical excitation and other potentials from the environment that avoids the need for EnOcean products to use a battery to operate.

Interoperability Proposals and Initiatives for Wireless Consumer Technologies

As it has been previously presented, the majority of the technologies developed for enabling communications have been designed as application/domain independent. That is, they provide a set of features that may suit specific requirements for an application or the related hardware implementation, but are not defined to meet them beforehand. Thus, in order to enable two devices or applications to seamlessly interact, an interoperability or domain-dependent application layer is required. The IEEE definition of interoperability is "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" [1]. Even though this abstract statement seems easily achievable, after looking at the previous technology snapshot it becomes a harder milestone and is still far from being completely implemented. In addition, even though two devices are connected using the same technology, it is not a trivial task to enable them to interoperate without the proper communication protocol so that an application-interoperability solution context is needed.

Historically, depending on the desired level of integration and application extension among other devices, this adaptation level can be proprietary or "standard" within the same technology (e.g., Bluetooth has adopted plenty of proprietary applications based on Serial Port Profile (SPP), which would be considered as a proprietary approach, while the definition of profiles, which, in fact, SPP belongs to, provides context-oriented integration mechanisms, and this example can be extended to USB or ZigBee). Thus, technology manufacturers have been developing proprietary solutions on top of these communication technologies so that a proper system functioning in a well-known scenario can be guaranteed, and Standard Developing Organizations (SDO), such as IEEE, IETF, ISO, IEC, etc., have supported this development by providing the necessary standard interoperability tools. In this context, a compilation of the major interoperability proposals and initiatives for the three considered domains is detailed in Fig. 2.

Entertainment

Wi-Fi offers interoperability through communication technologies such as DLNA and Wi-Fi Direct: DLNA allows devices to share and stream content over an existing wired/wireless network while high level applications are also possible through Plug-and-Play (PnP) for service discovery; and Wi-Fi Direct allows devices to connect directly by building their own wireless network unlike a conventional access point configuration. Bluetooth and ZigBee enable interoperability by defining application-context

The appearance of the "Web of Things" paradigm, led by the emerging 6LoWPAN and Internet-based technologies, proposes a new integration level, not only for the network (the previous "Internet of Things" vision), but also for the web.

profiles: for Bluetooth, Advanced Audio Distribution Profile (A2DP), Audio/Video Remote Control Profile (AVRCP), Video Distribution Profile (VDP), Headset Profile (HSP), Generic Audio/Video Distribution Profile (GAVDP), Basic Imaging Profile (BIP), and Basic Printing Profile (BPP), among others; and for ZigBee, Input Device, 3D Sync, Telecom Services, Network Devices, and Gateway, among others. WHDI enables wireless delivery of uncompressed High-Definition Television (HDTV) throughout the home in a homogenous way (Wi-Fi requires its DLNA interoperability layer) and provides consistent picture quality equivalent to wired HD Multimedia Interface (HDMI) cable, low latency, multi-room availability, and low-power consumption. WiHD allows uncompressed digital transmission of HD audio/video (Wi-Fi must rely on compression technologies), making it equivalent to a wireless HDMI but potentially adapted for portable devices, and high transfer rate (double that of WHDI). WiGig, with its recent certification-ready specification, will allow tri-band devices to wirelessly communicate at multi-gigabit speeds (seven times faster than 802.11ac and 10 times faster than 802.11n, while maintaining compatibility with existing Wi-Fi devices) enabling high performance wireless data, display, and audio applications.

Home Automation

Bluetooth has no specific application profiles for this domain, so most systems implement SPP, leaving an upper layer to be completed. ZigBee defines some profiles for this domain, such as Building Automation (efficient commercial spaces), Remote Control (advanced remote controls), Smart Energy (home energy savings), Home Automation (smart homes), or Light Link (LED lighting control), among others. IEEE 1451 establishes a set of standard interfaces that describe common, network-independent communication interfaces for connecting transducers and smart sensors to microprocessors. UPnP (ISO/IEC 29341) defines a set of upper-layer networking protocols to enable interoperability among networked devices, and seamlessly discover and establish functional network services.

e-Health

ISO/IEEE 11073, developed by IEEE/ISO and CEN/CENELEC and promoted by Continua Health Alliance and Integrating the Healthcare, defines a suite of full protocol stack for the interoperable communication of medical devices in higher layers, being transport-layer portable in order to allow adopting the specifically designed health device profiles for Bluetooth (Health Device Profile, HDP), ZigBee (Health Care, HC), and USB (Personal Health Device Class, PHDC). In February 2011, Continua Health Alliance signed a collaboration agreement with Wi-Fi Alliance for the promotion and adoption of Wi-Fi Direct technology, and more recently, did the same with the NFC Forum to expand standards-based connectivity technology in the health IT industry. HL7 is a set of protocols that, with the definition of a range of message types, covers the communication of a wide variety of clinical information between entities through the full OSI reference model and, specially integrated with ISO/IEEE 11073, provides a mechanism for connecting to external health information systems. ANT+ is a top-level interoperability layer that ensures compatibility through ANT+ profiles, by defining specific network parameters and data structure, so that ANT products from different manufacturers can communicate seamlessly. Sensium is a proprietary solution that defines a full protocol stack for enabling a wireless system for vital sign monitoring featuring low-power consumption where each device specialization is integrated as a module, such as heart rate, temperature, etc., up to 16 nodes. Zarlink is a proprietary solution that defines a full protocol stack system composed of an implantable RF transmitter for ultra-low-power consumption in accordance with the Medical Device Radio Communications Service (MedRadio).

At this point, it has been shown that enabling interoperability by means of defining application layers, introduces an additional fragmentation over the same communication technology lying at lower layers. A first approach at attempting to enable cross-domain integration involves establishing a homogeneous layer just before the application level in order to expose a common interface for the information exchange process. Although this may seem a direct implementation of a protocol shim layer for adaptation, the underlying technology layers and their architecture must therefore be considered. Both standard and proprietary protocols are differentiated in terms of the integration level relating to the OSI reference model, with some of them applied to lower layers (IEEE 802.3, IEEE 802.11, ANT, Bluetooth, ZigBee), upper layers (Extensible Messaging and Presence Protocol (XMPP), ISO/IEEE 11073 Personal Health Devices, ANT+, WiGig Protocol Adaptation Layers (PAL), Bluetooth/ZigBee profiles) or the complete stack (ISO/IEEE 11073 Point-of-Care, Digital Imaging and Communication in Medicine (DICOM), DLNA), as will be discussed in Section IV.

Trends and Challenges Towards Cross-Domain Integration

In an attempt to achieve value-added solutions in distributed networking scenarios such as home environments and using the technologies and interoperability initiatives previously detailed, numerous studies have been developed over the last decade. In [3] the authors propose a gateway architecture enabling devices in a DLNA-based home network to control devices in a ZigBee sensor network through DLNA. An intra-gateway for entertainment contents in Digital Home, based on UPnP to provide interoperability among different Digital Restrictions Management (DRMs), services and content formats is proposed in [4]. IEEE 1451 has been used by different research groups to try to solve particular problems in specific areas, as in [5], a project that studies integration between IEEE 1451 and

HL7 to exchange incompatible healthcare information generated from heterogeneous medical information systems. In [6], a multimedia service platform to create multisensory media effects for heterogeneous appliances and a home server in the ubiquitous home networks is presented. This work adopts UPnP to enhance compatibility among devices. In [7], a cross-domain application is proposed for a non-compliant ISO/IEEE 11073 PHD device, i.e., Nintendo's Wii Balance plus a virtual ISO/IEEE 11073 PHD weighing scale. The majority of these projects propose tailored technologies and protocols that make use of specific applications and, at upper levels, generic gateway architectures and abstraction layers to overcome the interoperability gap. Even though these types of approaches enable integration of non-compatible technologies [8], they are only isolated applications, suitable for specific scenarios.

The appearance of the "Web of Things" paradigm, led by the emerging 6LoWPAN and Internet-based technologies, proposes a new integration level, not only for the network (the previous "Internet of Things" vision), but also for the web. By using existing and ubiquitous web protocols as common ground, the resources of different devices can be used to create new applications, thanks to this open interface approach. In this context, there are mainly two prevailing architectural tendencies for building distributed systems, as stated in the Introduction: SOA and ROA. Choosing between these two approaches implies different advantages and drawbacks, as discussed in the following.

OASIS defines SOA as "a paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains. It provides a uniform means to offer, discover, interact with and use capabilities to produce desired effects consistent with measurable preconditions and expectations." SOA is based on a design paradigm that specifies the creation of automation logic in the form of services. Therefore, an architecture oriented to services facilitates the separation of problems. The popularity of SOA began with the advent of Web Services (WS), which enable interoperable machine-to-machine interaction over a network, by allowing different services to be homogeneously published, discovered and used in a standard technology-neutral form. WS are the most common way, albeit not the only one, for implementing SOA architectures, but it is important to underline that SOA does not imply using WS because they are different concepts [9].

There are several specifications associated with WS with different degrees of maturity, supported by various SDOs. These specifications are the basic WS framework established by first-generation standards: Web Services Description Language (WSDL), Simple Object Access Protocol (SOAP), and Universal Description, Discovery and Integration (UDDI). Specifications may further complement, overlap, and compete with each other. The Web Services Discovery and the Web Services Devices Profiles (WS-DD) [10], which are based on the Devices Profile for Web Services (DPWS), are noteworthy efforts among the profiles occasionally referred to as "WS-*. DPWS defines a lightweight subset (WS-Discovery, WS-Eventing, WS-Transfer, WS-Security and WS-Policy) of profiles within the WS suite, which are oriented to embedded systems and devices with limited resources. The main disadvantages of DPWS, as discussed in [11], are the overhead, since it uses eXtensible Markup Language (XML) for data representation and the SOAP-over-HTTP binding for the communication part. To overcome these limitations, the proposal in [11] presents an enhanced procedure that comprises the Efficient XML Interchange (EXI) compressor and the SOAP-over-CoAP binding for transport of SOAP messages in resource constrained environments.

Most of the platform proposals for integration, especially in Wireless Sensor Networks (WSN), implement SOA. For instance, in [12], a service-oriented architecture for delivering e-Health services at home using a hardware platform such as a residential gateway is proposed. In [13], a solution to connect isolated Open Services Gateway Initiative (OSGi) frameworks and support the usage of native DPWS devices and services is presented. In [14], DPWS is integrated as a comprehensive middleware for e-Health devices, and [15] describes a DPWS-based open architecture for home service development. In [16], a framework to design and implement integrated services for home network appliances with SOA, although not using DPWS, is proposed. Finally, [17] presents a design and implementation of a SOA that integrates UPnP and DPWS in an OSGi framework and using ZigBee and Bluetooth to merge a number of service oriented applications.

ROA is a specific set of guidelines for implementing a REpresentational State Transfer (REST) architecture, which uses similar architectures to the web. As opposed to REST, SOA is essentially designed to separate functions or automation services. A SOA architecture, consisting of a number of services, merges such "functionalities" into one overall feature. However, REST standardizes the traditional functions, i.e., GET, PUT, POST and DELETE (in case of HTTP connectors). REST is not defined upon method definitions, but it requires methods to be uniformly defined for all resources (i.e., intermediaries do not need to know the resource type to understand the request). Therefore, the implementation of a RESTful service is usually easier and more lightweight than in SOA.

These features could lead designers to believe that REST is the most interesting candidate to build a universal and interoperable interface for smart things. However, implementing RESTful architectures for communication between devices is a complicated task and still requires further research efforts (some related results are presented in [18]). A major drawback is the way that ROA architectures perform asynchronous messaging [19]. Nevertheless, a number of alternatives to overcome this limitation are proposed in [20]. As mentioned above, choosing an architecture depends on the type of application to be developed. An existing evaluation study concludes that REST is an architectural style for the web, while SOA can be used to build a middle-

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ware of interoperable standards [21]. One of the most important applications of applying the REST architectural style is the development of physical mashups [22], which can be defined as applications that seamlessly integrate different data sources on the web. Mashups feature some characteristics, such as:

- Accessibility — devices are modeled as resources of the web under different representations.
- Findability — resources are indexed by search-engines (lightweight-metadata).
- Sharing — data are shared through Social Access Controller (SAC) architectures using different web applications (such as Friends and Things, FAT).
- Composition — data are a combination, a presentation or a functionality derived from two or more sources for creating a new service.

There are several examples of physical mashups in the Internet, such as: Sensorpedia [23], which provides enterprises and organizations with methods to share sensor information solving the actual lack of PnP features applied to data sources; Pachube [24], which gives people the power to share, collaborate, and make use of information generated from the world around them; or Sensor.Network [25], which allows researchers and scientists to share data with authorized partners, which can manage sensor installations, visualize collected data and share it with trusted partners.

Another possibility to provide formal and high-level interoperabilitty is the use of ontologies. An ontology defines a set of representational primitives for modeling a domain of knowledge [26]. The main purpose of the semantic web and ontologies is to integrate heterogeneous data and enable interoperability among disparate systems. Ontologies are used to model software engineering knowledge by denoting the artifacts that are designed or produced during the engineering process. Essentially, an ontology makes it possible to share common understanding of the structure of information among people or software agents, to enable reuse of domain knowledge (e.g., to share the same concept in different domains), to make domain assumptions explicit, to separate domain knowledge from the operational knowledge, and to analyze domain knowledge.

In this context, [27] suggests an approach in which each node of the WSN has a repository that stores semantic information regarding low and high-level resources. Such repositories are hierarchically organized, according to a cluster topology. Simple services and available physical resources are stored in the most basic level of knowledge. On top of that, basic services, composition rules and workflow plans to organize contextual services and information are stored in the second. On top of that, all semantic parts for building the contextual model of the entire network are stored in the third level. This repository is usually located in the gateway that connects the sensor network with other available physical networks. In [28], an application layer solution for interoperability among heterogeneous devices using semantics provided by existing specifications and dynamically wrapped into semantic services is proposed.

Mashups and ontology-based solutions are not mutually exclusive. For example, as proposed in [29], the automatic generation of mashups based on an ontology-based model, can be merged.

Conclusion

This article provides a comparative overview of the main wireless communication technologies for consumer networking that can be applied in home environments such as entertainment, home automation or e-Health. Since transport technologies are not enough to exchange disparate information seamlessly, high-layer interoperability protocols are required. Therefore, this work also describes a comprehensive compilation of the major interoperability proposals and initiatives for the considered domains. Nevertheless, a higher application layer is also required if cross-domain integration is to be achieved. Consequently, a reasoned discussion of tendencies on abstraction-based architectural approaches that can be used to overcome the concerns that arise because of the fragmented, isolated realities of low-layer stacks are also covered within this manuscript. As a result, a complete protocol stack overview, from available transport technologies to existing and emerging architectural approaches, is also discussed by putting at the disposal of the readers a useful tool to select an appropriate combination of technologies, standards, and architectures for their complete stack.

Acknowledgments

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Biographies

Antonio Aragüés (aaragues@unizar.es) received the MS degree in telecommunication engineering and M.S. degree in biomedical engineering from the Aragón Research Engineering Institute (I3A), University of Zaragoza (UZ), Spain, 2006 and 2010, respectively, where he currently works. His research interests include e-health, mobile solutions, multimedia services, wireless communications, biomedical applications and architectures, and interoperability and standardization, where he has developed several research projects within the I3A research line of telemedicine.

Ignacio Martínez (imr@unizar.es) was born in Zaragoza, Spain, in 1976. He received the MS, DEA, and Ph.D. degrees in telecommunication Engineering and bioengineering Doctoral Program from the Aragón Research Engineering Institute (I3A), University of Zaragoza (UZ), Zaragoza, Spain, in 2000, 2002, and 2006, respectively. His research interests include telemedicine, quality of service on multimedia services and interoperability and standardization, where he is a Coordinator of standard-based solutions for e-Health services with more than 30 published papers.

Pilar del Valle (pdelvalle@unizar.es) was born in Zaragoza, Spain, in 1984. She received the M.S. degree in telecommunication engineering and M.S. degree in biomedical engineering from the I3A, UZ, Spain, 2009 and 2010, respectively, where she currently works. Her research interests include e-health, biomedical applications, interoperability, standardization, e-accessibility and usability, where she has developed several research projects within the I3A research line of telemedicine.

Pilar Muñoz (pmg@unizar.es) received the MS degree in telecommunication engineering and M.S. degree in biomedical engineering from the Aragón Research Engineering Institute (I3A), University of Zaragoza (UZ), Spain, 2008 and 2010, respectively, where she currently works. Her research interests include e-health, electronic health record systems, clinical models, interoperability and standardization, where she has developed several research projects within the I3A research line of telemedicine.

Javier Escayola (javier.escayola@unizar.es) received the MS degree in telecommunication engineering and Master's degree in biomedical engineering from the Aragón Research Engineering Institute (I3A), University of Zaragoza (UZ), Spain, 2005 and 2008, respectively, where he currently works. His research interests include e-health, mobile applications, multimedia services, wireless communications, biomedical applications, and interoperability and standardization, where he has developed several research projects within the I3A research line of telemedicine.

Jesús D. Trigo (jtrigo@unizar.es) was born in Zaragoza, Spain, in 1981. He received the M.S. degree in telecommunication engineering from the University of Zaragoza, Zaragoza, Spain, in 2005, and Ph.D. degree in Biomedical Engineering from the University of Zaragoza, in 2011. His research interests include e-Health applications and architectures, biomedical informatics or medical device interoperability and standardization.