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Smart Buildings Using IoT Technologies

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ABSTRACT

The need for remotely accessible data and information/knowledge about technical performance of buildings, at any time, from any place, regardless the type of parameters, together with the need of complete remote control will lead to the development of "Internet of Things" (IoT) for buildings. "Intelligent Buildings" (IB) are envisaged by this technology in order to optimize their performances over the life-cycle. A solution regarding to the architecture of an IoT network for IB and an experimental testing bench for one of the first steps leading towards implementing the IoT for integrating components and subsystems of IB and networks of IB is briefly introduced in this paper. An overview about IB and future trends in this sector is introduced in the first part of the paper. Current developments on IoT are further highlighted. A generic architecture of IoT and the way it could be implemented into intelligent building systems are afterwards presented. Implementation and testing of the solution for connectivity between a distributed network of smart components of IB and an Android compatible monitoring device covers the next part of the paper. Tests have shown that the proposed concept is functional. Paper ends with conclusions, as well as with the roadmap for concept implementation.

Contents

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1. Introduction

Intelligent buildings (IB) have received increasing interest over the last 25 years, as various IB technologies have been developed [1]. Various bodies took the responsibility to define IB. Some of them, like European Intelligent Building Group (UK) or Intelligent Building Institute (USA), are focused on IB from performance perspective [2]. Thus, the focus from this point of view is on user comfort, capability to adapt quickly to changing needs of the users, efficient management of resources and minimization of life-cycle costs. Engineers must decide which technologies should be considered such as to meet these challenges.

Japanese Intelligent Building Institute sees IB from service-to-user perspective. Here the focus is on providing more attractive administrative services at lower costs, as well as flexible and economical responses to sociological changes [3].

A third perspective is given by the Chinese IB Design Standard GB/T50314-2000, where IB is seen from technological point of view (building automation, office automation, communication automation, safety, and convenience) [4].

Despite various definitions, IB should be seen from a multi-industrial standpoint, involving the right combination of architecture, structure, information technology, automation, environment and energy, services and facility management such as to minimize life-cycle costs, maximize comfort and adapt properly to cultural stimuli [4,5]. Intelligent architecture concerns with intelligent design to meet cultural and contextual requirements, with proper use of IT and smart technology, as well as with optimal building exploitation and cost-effective maintenance over its life-time [6]. This might also include intelligent and responsive facades. Facility management looks for the best financial management for maintenance, rebuild and renovation, for the best space utilization, for the best daily operational services and for maximizing user satisfaction [3].

From information technology and automation dimensions, IB could be analyzed in terms of technology sophistication and integration on various layers [4, 6]. The bottom layer refers to dedicated non - integrated/independent systems like security control, light control, lift control, access control, telephone, fax, internet, data and communication management, etc. The immediate superior level is related to integration of several functions, like security and access, light and temperature, voice, data and image. The next level ensures a complex integration at the building level, including remote access via modem. Integrated building automation systems and integrated communication systems are good examples in this respect. With the development of technology, much higher integrated solutions are possible, like computer integrated building, which uses remote access via internet and cellular communication for data and voices. The top level is the integration of all building functions to a global network of buildings, including internet and wireless protocols for data, voice and image communication, expert systems for remote optimal management of building functions, tele-monitoring and tele-service/tele-maintenance. Reconfigurable smart components and systems for IB are required at this level [7].

In this agenda, the objective of the present paper is to introduce a technology with high potential to move IB towards a next generation model. It is based on “Internet of Things” concept (IoT) adapted to IB in order to integrate smart reconfigurable components and subsystems of IB into an Enterprise Network Integrated Building System (ENIBS), as well as, if opportune, into global networks of ENIBS. The article is organized as follows. In section 2 a review on IoT is considered. It is shown that IoT is still at its beginning and no relevant contributions on applying IoT on IB or, even more, on ENIBS, are reported in this respect. Section 3 presents the methodological framework for designing a generic architecture for IoT with applicability in IB and a generic architecture for reconfigurable smart plug-and-play control system for rapid integration and configuration of smart IB components. Section 4 is dedicated to experimental testing of the theory. Paper ends with conclusions and ideas for future researches.

2. Background on IoT for IB

The term “Internet of Things” (IoT) describes a system where the digital world is connected to the physical world forming a global network [8, 9]. IoT exploits sensors, actuators, and data communication technology embedded into physical objects (e.g. in the case of IB: doors, walls, furniture, windows, facades, lifts, ventilation modules, heating/cooling modules, lighting modules, water systems, roofs, electrical power systems, communication systems, equipments and devices for office use, data storage systems, etc.) that enable those objects to be tracked, coordinated, or controlled across a data network or internet with the goal of creating value for the user over the system life-cycle [10].

More and more, IoT is foreseen as the solution for the ever-increasing demand for connectivity between peoples, organizations, companies, gadgets and devices and it was born from the desire to achieve real-time control and access to information for optimal and intelligent management of integrated resources.

Based on machine-to-machine (M2M) connectivity concept, fuelled by the development of smart sensors and actuators, together with communication technologies (Wi-Fi, Bluetooth, RFID) and supported by cloud computing technologies, IoT becomes a reality and its goal is to make "things" more aware, interactive and efficient for a better and safer world. Therefore, any smart device that can be addressed by means of a communication protocol can be part of the IoT.

European Union research cluster on Internet of Things, defines "things" as active participants in any kind of "business, information and social processes where they are enabled to interact and communicate among themselves and with the environment, by exchanging data and information 'sensed' about the environment, while reacting autonomously to the 'real/physical world' events and influencing it by running processes that trigger actions and create services with or without direct human intervention" [11].

Therefore, the IoT is both a reactive- and proactive-to-change layer of digital information, covering the real world and connecting to it. Extensive research and great amount of time and financial resources have been invested by corporations and governments into this concept, which is also refereed as the next technological revolution [12]. According to Gubbi [13], IoT is composed out of three main parts, linked by communication networks: physical devices (things) with an identity that can be accessed, monitored and controlled; middleware, the layer that links the physical world with the virtual world; monitoring and control/information systems. Figure 1 illustrates the generic concept of IoT.

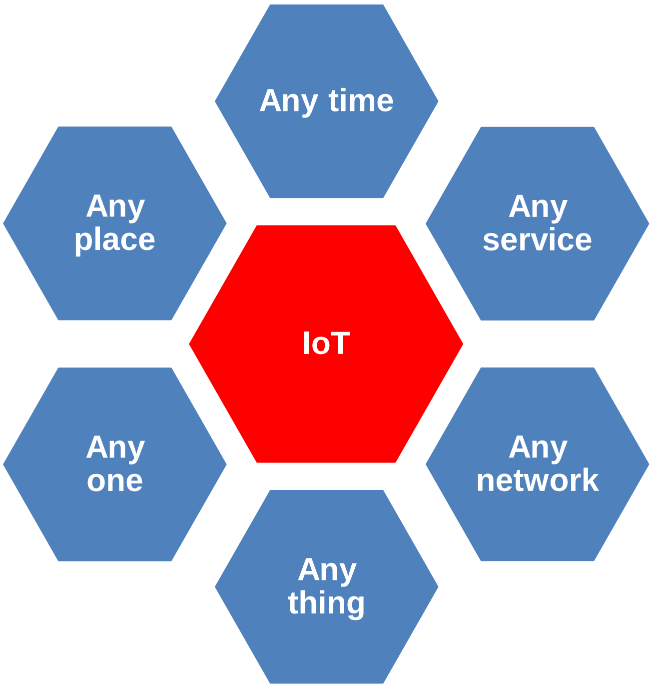

Figure 1. Generic concept of IoT [12]

Even if there are great challenges to overcome, roadmaps and strategic research planning are established and the Internet of Things is about to become "the nervous system of the planet" [14]. The value of a network is given by the following equation: Network value = #Connections2 [15]. Considering the tremendous number of things that can be connected in an IB, the importance of IoT within IB is of great significance. Several architectures to implement IoT are proposed in [13, 16 - 18]. Nevertheless, all of them can be synthetized in a simple way as in figure 2.

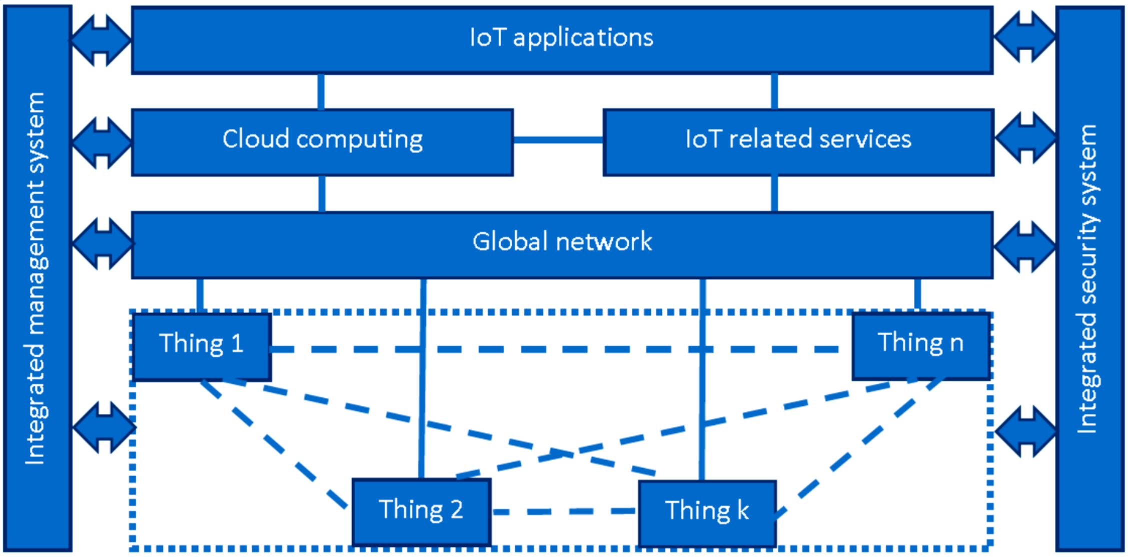

Figure 2. Simplified IoT architecture

The European IoT research cluster gathered under a strategic research roadmap the technology enablers and the issues that need to be addressed towards achieving the actual goals of IoT concept [11]. The goal of the research introduced in this paper is to deliver connectivity to reconfigurable smart IB components/devices such as to be controlled and monitored by software applications running on mobile devices (here Android compatible) in order to increase the mobility for facility management, to ensure flexible remote data management and faster decision making in case of crises. Therefore, among identified enablers and issues that need to be addressed, those of interest for this research are highlighted below:

– Networks of smart IB components/equipment enhanced with embedded distributed intelligence to deal with scalability challenges [11],
– Micro-electromechanical systems and sensors for augmented applications in IB and building automation [19] or foreknowledge and awareness of things to come [11],
– Interoperability for efficient IB components communication [11],
– Extended communication capabilities for intermittent network connectivity and unique identification of IB modules and components [11],
– Energy efficient and reconfigurable IB modules [11],
– Remote human machine interaction and interfaces; maintenance service and support for IB [11],
– High computational power and information processing, data storage and data availability [11, 19],
– Plug-and-produce IB modules and components [11].

Reconfiguration paradigm applied on IB refers to the ability of the IB to quickly reconfigure its resources in order to obtain a reliable system with a desired functionality as a response to user and/or environment changes or other requirements [19]. The reconfiguration paradigm is based on six core functions.

– *Modularity* is a key enabler of reconfigurable systems (RS) of IB and reconfigurable units/module (RU) and refers to a system property that would allow creation of complex systems out of basic hardware and software modules.
– *Integrability* represents the ability of RS and RU to reliably cooperate with actual and future developed technologies regardless the producer.
– *Convertibility* is the ability of a RS or RU to manage its resources to quickly changeover between existing tasks or shortly adapt to upcoming tasks.
– *Diagnosability* is a core function that allows tracking down and troubleshooting functioning problems. Self-diagnosis is an important extension of this core function.
– *Customization* represents the ability of RS or RU to continuously adapt to varieties of tasks and technologies and in order to quickly respond to new requirements.
– *Scalability* is the propriety that allows adding or removing components or functionalities reliably.

Employing the above mentioned core functions it is possible to obtain an advanced control architecture containing simple, intelligent units, with valuable characteristics. Building RU is not a simple task. RU should not be confused with modular units. Far beyond modularity and fast connecting joints, RU must possess the ability to quasi-instantaneously transfer information between its modules and from each module to the master controller continuously or at least periodically, when this is required. Information is complex, it referring to several issues like: position of each module relative to those that are interfacing with, history of each module in terms of the previous use, current state in terms of failure monitoring and control, dynamic data, accuracy data and calibration requirements, etc. Moreover, the master controller must possess the ability of scalability and convertibility. These aspects clearly require local embedded smartness, by using hardware and software means, as well as adequate algorithms and communication protocols to effectively build intelligence into the system. In this specific topic of reconfiguration, very few notable results are reported [20, 21].

Beyond these issues, in ENIBS, long distance service and maintenance is another significant challenge. Effective links between RU producers and RU users will be done via tele-engineering mechanisms (including remote monitoring and control, remote maintenance, remote service).

This requires implementation of adaptive sensory systems to the level of RU, optimal placement strategies of the sensors, efficient data compression and pre-processing stages to support the monitoring agents (watch dogs) performing simple, on-line and real-time process change detection, clever methodologies for information management, use of information for self-learning purposes, on-line adjustments to maintain accuracy instead of simply monitoring degradation, simplified diagnosis algorithms, etc.

3. Problem approach

To tackle with the challenges before mentioned two general design conflicts should be considered:

- Conflict 1: increased reconfiguration while keeping low costs integration;
- Conflict 2: increased adaptability while keeping low costs integration.

For the first conflict, the innovation proposed by TRIZ method is to change the concentration of functions and modularity. For the second conflict, three areas of interventions are proposed by TRIZ: to change the concentration of functions, to develop non-uniform structures and to make some characteristics of the components changing in time and/or space. Therefore, the idea was on developing sensors, motors and other units that are self-intelligent, able to carry information about their own past events, and information about their geometric, kinematic and dynamic characteristics (including offsets). Moreover, these intelligent units have to change some of their functions (by means of software algorithms and data). In addition, they have to incorporate an interface for communicating quasi-instantaneously with other intelligent units for self-reconfiguration in the new configurations of the RU. The idea to use buffers for avoiding the loose of information brings huge benefits in terms of system reconfiguration during its running. These ideas are reflected in the solution presented in figure 7.

4. Research results

Our vision and the proposed architecture for deploying IoT into the IB field is presented in figure 3, based on several connected research topics in the area of the above mentioned IoT enablers and challenges [19, 20] and [21]. For a better clarity, some layer of the proposed architecture are not presented, among them being: security, middleware and overall information management.

As depicted from figure 3, an ENIBS is built out of smart reconfigurable resources that are linked by means of wired or wireless communication between them and to the system control and information management layer. Sensors and actuators are part of reconfigurable resources, which, if joined together, can create a more complex resources obtaining extended functionalities. Smart reconfigurable resources can be considered things because they are addressable by using a communication network (wired or not) and they have the ability to process, store, send and receive data and monitor or control devices (sensors, actuators, etc.). Even more, they have the ability to communicate with other reconfigurable resources and react to changes in order to maintain a specified process parameter set-point by different means.

A smart reconfigurable resource is enhanced with distributed intelligence, providing local control for the physical resource, plug-and-play capability and high computational power. Even more, the hardware and software building blocks of a reconfigurable resource can be rearranged in order to obtain a different then before functionality with a minimum effort and delay.

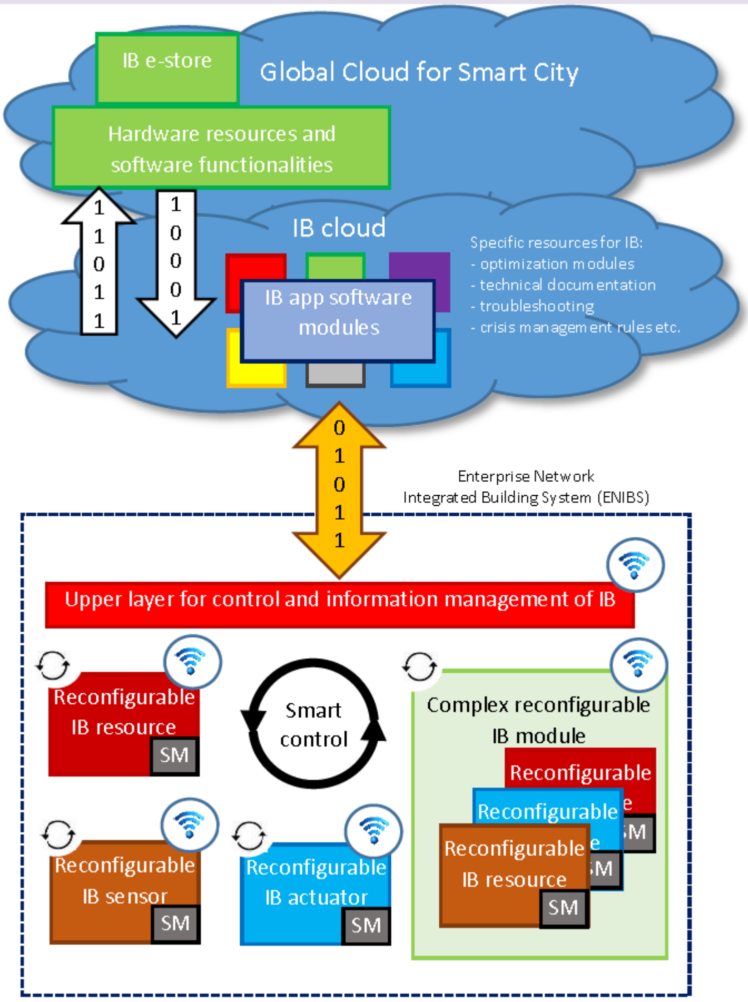

Figure 3. Simplified IoT architecture for IB with RU in an ENIBS

Figure 4 presents an overview of a conceptual architecture for smart resources. Several experimental developments for deploying smart reconfigurable equipment and control architectures have been already done by the authors of this paper and published in [19 - 21].

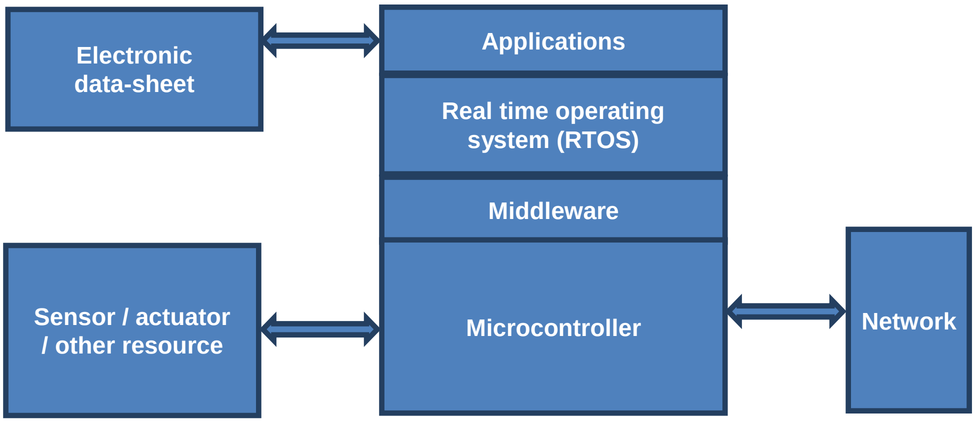

Figure 4. Block scheme of a smart reconfigurable resource for IoT

The IB cloud is designed to be a service that will connect the ENIBS or an IB resource to a larger unit (e.g. smart city). It is envisaged to provide access to computing services, process information, IB software applications and to support data sharing with the served process, but, not restricted to this. Enterprise (e.g. smart city) cloud will allow one to remotely connect to a specific IB resource, monitor its status, enhance software algorithms or download new ones.

Global cloud represents the global network of intelligent buildings and systems, whereas an enterprise could sell or buy software and hardware IB resources, technical support and data. There are three major expected outputs from the proposed architecture. First, the development of smart reconfigurable resources, allowing rearranging their constitutive blocks in order to fit process needs by selecting the right software applications from the global or IB cloud within the constraints of the available hardware modules. Out of these resources, more complex reconfigurable IB resources can be achieved, leading also to reconfigurable IB systems. Their development will be supported by highly interoperable modular hardware and software blocks, generic embedded systems, real time embedded operating system, intelligent information management algorithms and informational-electrical-mechanical interfaces.

The second output is the graphical human-process interface, which will provide a more enjoyable user experience to the IB processes by means of PCs, smart phones and tablets. The interface will be used to design control algorithms for reconfigurable resources or to its modules, by using the software functionalities and technical resources available in the ENIBS cloud or IB e-store. The control algorithm will be transferred to the resource for which it was designed throughout the computational resource of the upper control and information management layer of the IB system. This layer will be responsible for several activities: to auto-integrate the newly connected reconfigurable IB resources, to support the operator in the configuration process of the newly connected IB resource, to provide the framework for designing control algorithms, to transfer control algorithms to the IB resource, to monitor the data received from the IB resources and to take over the control of IB resources if needed.

Third, the IB cloud will be the virtual space of the IB industry. It will provide an ENIBS with access to an IB e-store, allowing it to acquire, sell, test and develop hardware or software resources and know-how. The global cloud will be the virtual model of a specific ENIBS that will link the IB cloud with the ENIBS facilities. It will host information related to the ENIBS and its processes, a database with available software functionalities that can be downloaded into hardware resources and a knowledge base with technical resources and troubleshooting actions, etc.

Among the first steps towards implementing the proposed architecture is the implementation and testing of the chosen connectivity solution. This part will focus on controlling and monitoring of an IB resource using an Android compatible device. Therefore, we expect to successfully deliver at least the following IoT characteristics as presented in figure 1: anytime, anyplace, anyone and partially any network.

Therefore, for this step, an embedded system was design around an ATmega32U4 microcontroller running at 8 MHz at which several sensors can be connected. By deploying specific software algorithms and an intelligent information management, these sensors will become smart sensors [20].

The UART communication protocol of the microcontroller was configured to work at a baud rate of 115200 bits per second 8 bit data, without parity and flow control and 1 stop bit. On the UART communication interface a wireless shield from Roving Networks (RN-171ek) was connected as a data gateway from the embedded design to a wireless network, as depicted in figure 5.

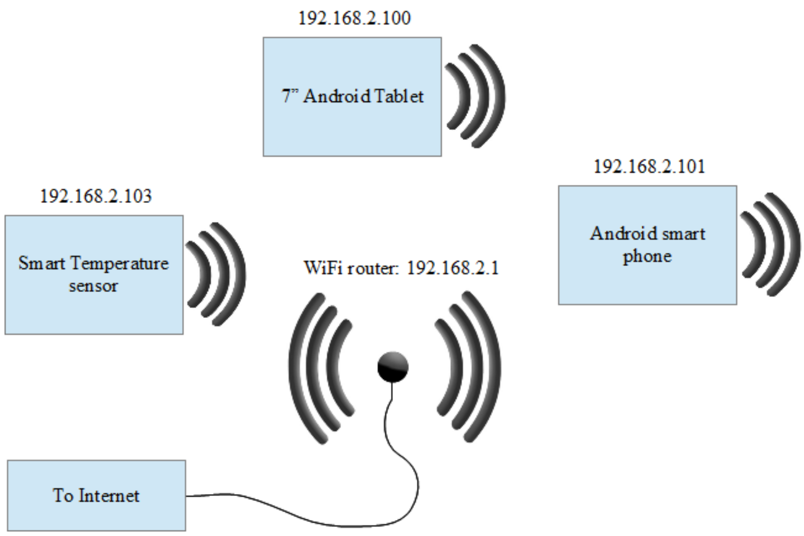

Figure 5. Wireless connection block scheme

An LM35 temperature sensor is connected to the embedded design and its reading is sent to an Android compatible device. In this case, the Android device is a 7 inch tablet. A software application from roving networks is used as a terminal in order to check if data sent from the embedded design via the WiFly shield reaches the device. The above mentioned wireless shield incorporates a 2.4 GHz radio processor, full TCP/IP stack, real-time clock and supports FTP client, DHCP, DNS and HTML client protocol. Secure Wi-Fi authentication with WEP, WPA-PSK and WPA2-PSK and configuration over ASCII codes via UART interface.

Figure 6 shows a screenshot from an 7” Android compatible device with information sent from the embedded design. The TCP/IP connection partner IP is 192.168.2.103 and the listening port is: 2000.

Figure 6. Terminal of an Android compatible device

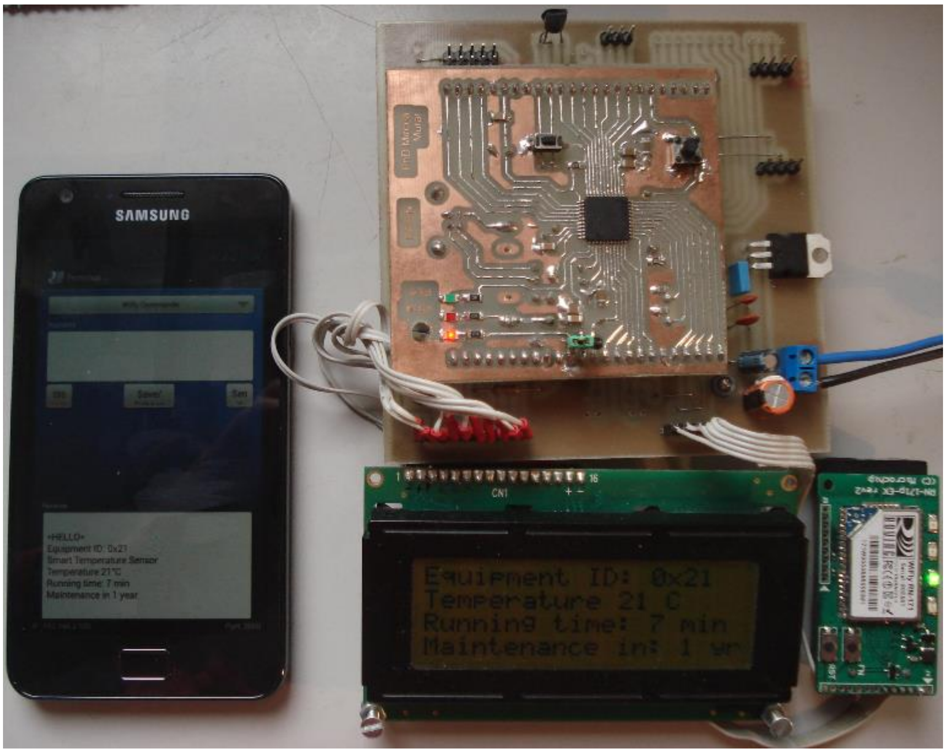

Figure 7. Experimental workbench

Figure 7 presents the experimental workbench composed out of an embedded design having an LCD for local display of process information, together with an Android compatible smartphone. Within figure 7, one can see: an android smart phone (1), an embedded system (2), a Wi-Fly module (3), a local display (4), and a LM35 temperature sensor (5).

Tests have shown that the proposed connectivity solution between the IB resource and a monitoring device meats our needs at this moment. Process data, in this case temperature, has been successfully transferred using the Wi-Fi shield (from Roving Networks) from an embedded design and two Android compatible devices, used for monitoring. As it can be seen from figures 6 and 7, the user or operator has access to additional useful information like: the time since the embedded design or IB resources are on, and information about maintenance of the resource.

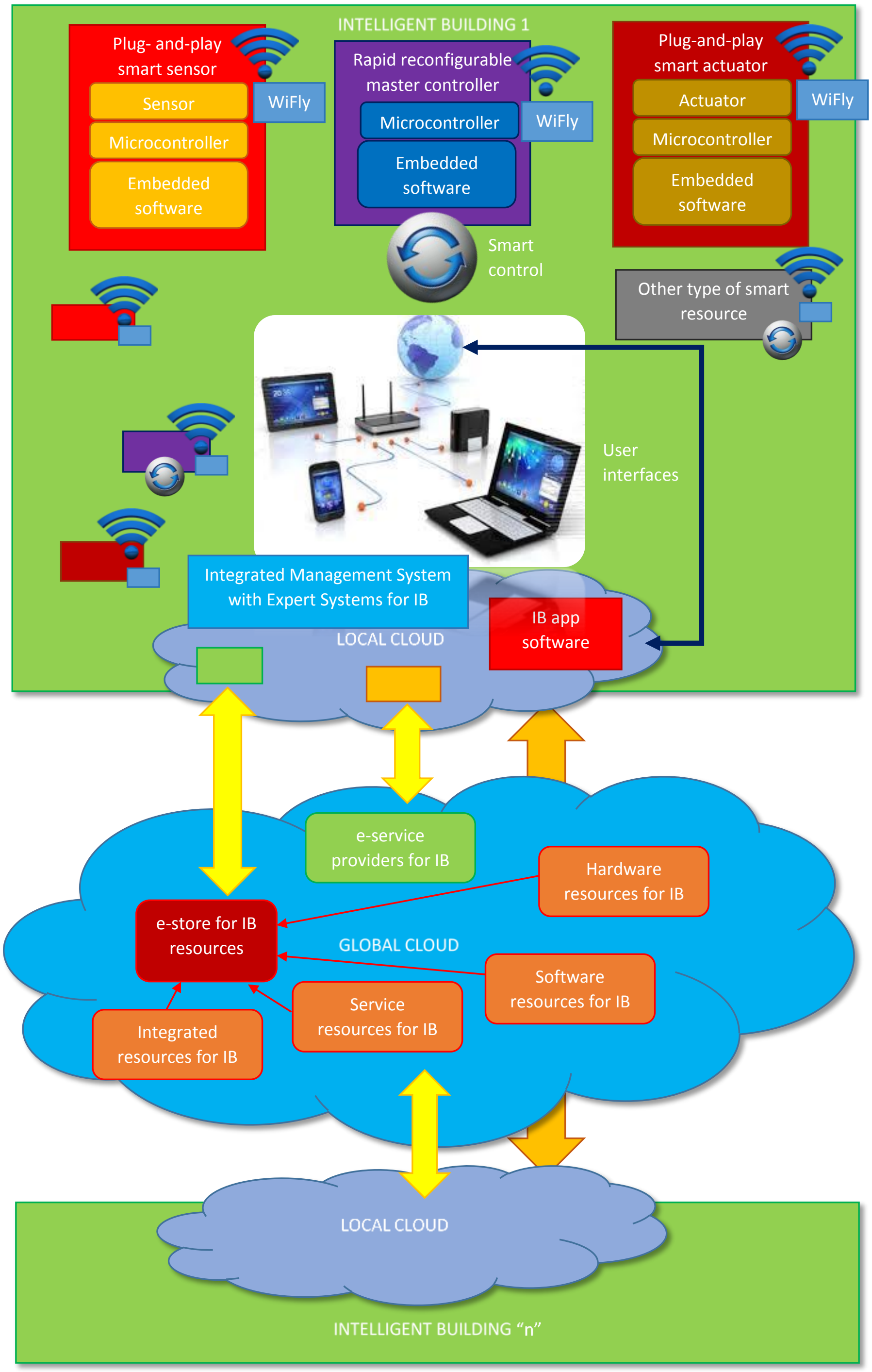

Figure 8. The enhanced concept for ENIBS

The enhanced concept of Enterprise Network Intelligent Building System is shown in figure 8. All units responsible with data collection (smart sensors for servicing various tasks: ventilation, heating, power supply, security, access, water, equipment, smart units for image recording and analysis, units for voice recording, etc.), task execution (smart actuators for building automation: doors, windows, walls, roofs, floors, lifts, stairs, etc.) or other functions (e.g. smart facades, smart walls, etc.) are wireless or wired connected to smart master controllers and/or to smart devices (e.g. tablets, phones, laptops). Master controllers can also communicate each other. Master controllers are rapid reconfigurable and any smart unit can be connected or disconnected quasi-instantaneously to/from the related master controller. The embedded software of each smart unit and master controller includes the logic for configuration and process management in relation with the given tasks. Master controllers are connected to various mobile or fixed devices which provide the interface with the user, as well as access to the local cloud resources. In the local cloud are stored various applications for managing all functions of the building. Expert systems are included to ensure optimized decisions and ensure the intelligent integrated management of all building functions. Various services and resources, as various levels of customization, integration and sophistication can be accessed from the global cloud. Intelligent buildings from a network of buildings (e.g. smart city) can communicate each other directly or via the global cloud, depending on the implemented architecture of the management system. Thus, buildings can transfer information and resources (e.g. energy) each other. Various backup systems must be also considered, as well as redundancy in the case of critical functions.

5. Conclusions

This research introduces a control architecture for IoT that enables building up intelligent resources for fast integration within IB systems. Intensive testing on the case study for recognizing specific characteristics has shown that the proposed control architecture is functional, highly reconfigurable, cost-effective, and the concept of IoT in IB is feasible. Some of the features of great importance in dealing with future IB system problems can be also found in our experimental test bench: *reconfigurability*, the control unit has the capacity to configure on-the-go and at any time the direction IN or OUT (i.e. the connection to the external world) with respect to the connected devices; the operator can ask a specific connected smart device (e.g. a sensor with its microcontroller) to provide its configurability options and choose between these options a desired way of how a device will act with respect to the implemented software and hardware configuration; *plug-and-play*, the control unit detects when a device is disconnected or connected on the communication system and takes care to integrate and configure the connected part without corrupting data transfer on the communication system; *real-time assistance*, all information about a device is inside the memory of the attached microcontroller, thus connecting two or more incompatible devices will result in alerting the operator and blocking any attempt of driving or controlling that device; *independent decision taking*, like preventive actions, in the case of smart units it is based on process information and data statistics regarding process values. The level of *decentralization* is another important feature identified in our design. It is obtained from the symbiosis between the given IB resource and a microcontroller connected by a communication network to other IB resources and to the higher management level. An average of 5 minutes is needed to the operator to configure the connected IB resource.

Based on the results of this work and our vision about how IoT can be implemented into the IB field, the following future research directions are established: to develop an intuitive, use-centered graphical human-machine interface for Android devices that can provide extended access and control to information stored within the embedded design and to its functionalities; to develop software applications that can be downloaded from the global cloud to an IB resource and used by this resource for process control and monitoring; to develop a network of IB resources for scalability implementation.

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Умные здания с использованием IoT технологий

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АННОТАЦИЯ

В настоящее время возникла потребность в получении информации о технических характеристиках зданий, которые могут быть доступны в любое время и из любого места. Здесь имеет место развитие технологии «Интернета вещей» (IoT). В первой части статьи ведется обзор интеллектуальных зданий и прогноз будущих тенденций их продвижения в строительной сфере. Рассмотрена общая структура IoT и то, как эта технология может быть реализована впоследствии в интеллектуальных системах в строительстве. Был проведен ряд тестов и осуществлено внедрение проекта. Проведен мониторинг интеллектуальных компонентов IB и Android. В заключительной части подведены основные итоги исследования, а также представлены дорожные карты реализации концепции.

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