A smartphone-centric approach for integrating heterogeneous sensor networks

Gianluca Aloi
DIMES - University of Calabria
Rende, ITALY
aloi@dimes.unical.it

Giuseppe Caliciuri
DIMES - University of Calabria
Rende, ITALY
gcaliciuri@dimes.unical.it

Giancarlo Fortino
DIMES - University of Calabria
Rende, ITALY
g.fortino@unical.it

Pasquale Pace [*]
DIMES - University of Calabria
Rende, ITALY
ppace@dimes.unical.it

ABSTRACT

Modern communication scenarios are increasingly based on common "*on the market*" smartphones in which several radio interfaces can be activated to acquire data coming from different environmental, health and lifestyle sensors; however, the fully compatibility and integration into a unified *Multi-S*tandard, *Multi-I*nterface and *Multi-T*echnology communication framework ($Multi\ SITCOM$), is still a challenging issue to be addressed. Looking at the evolving present-day context, the main contribution of this work is twofold: *i)* first, we design and implement a general smartphone-centric, high-level, unified and extendible software architecture for data sensor collection, processing and forwarding *ii)* then, we evaluate the feasibility of the proposed architecture, throughout a specific testbed, by measuring system performances in terms of energy consumption, CPU and memory usage. The obtained results validated the soundness of the proposed approach presenting a low usage of hardware resources (CPU load $\approx$ 14% and memory occupancy $\approx 45MB$) even if, the major consumption introduced by the radio interfaces and the low capacity of current batteries, significantly reduce the smartphone lifetime.

Categories and Subject Descriptors

C.2 [**Embedded and cyber-physical systems**]: Sensor Networks; D.2.8 [**Software Engineering**]: Metrics—*performance measures*; L.4.3 [**Ubiquitous and mobile computing**]: Smartphones

Keywords

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[*]Corresponding author

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1. INTRODUCTION

In recent years, many aspects of daily life have been the subject of attention of the most important technological players on the market. Today, many investments will continue to move towards the search for technological solutions that allow an in-depth interaction between individuals and their surrounding world. Therefore, one of the main objective for the coming years will be to provide to each person the opportunity to have on hand the full control of their own lives and their living space.

Almost daily, we witness the blossoming of new applications and new devices capable of interacting with people, environments and, especially, with other devices. Terms like smart-home/building, body sensing, mobile-health/fitness, etc... are becoming more and more familiar, even if behind these terms are hidden many technologies and devices, often very different between them and still difficult to integrate. At the same time, we are seeing growing the proliferation of several smartphone applications able to harvest and handle data coming from different sensors with the aim of making the user constantly aware of his biomedical condition or monitoring environmental parameters such as light, pressure, temperature, etc... Although a plethora of different wireless sensors is nowadays available on the market, they use different communication standards and transmission technologies, in many cases, well designed for specific applications. For this reason, the full compatibility and integration into a unified communication framework of such different devices, is still a challenging issue to be faced also considering the strict constraints in terms of energy consumption and reduced computational capabilities.

Starting from this exiting and modern communication context, we first propose ($Multi\ SITCOM$), a specific multi-standard, multi-interface and multi-technology communication framework able to integrate different standards and radio interfaces in a whole platform; then we describe a software architecture for developing a complete smartphone-centric application and finally, we implement a real testbed in order to measure the performances of the proposed smartphone centric application in terms of energy consumption and resources occupancy with the aim of drawing significant discussions on the real feasibility of such integrated communication architecture.

The rest of the paper is organized as follows. In section 2 we review recent literature of software platforms for healthcare and environmental applications by highlighting the lack of an integrated solution. In section 3 we propose an integrated communication approach based on a smartphone-centric application able to handle and use all the communication interfaces in a unified fashion. In the same section we also describe specific software modules and components within the proposed software architecture. The testbed implementation and the measured performances are shown in section 4 whilst the section 5 concludes the paper presenting few open research issues.

2. MOTIVATIONS AND RELATED WORKS

Nowadays exists a plethora of communication solutions and standards that meets sectoral needs which refer to worlds that do not talk among themselves. In fact, big player such as *Polar*,*TomTom* and *Garmin* are focusing their major attention on wellness solution market, while other big player like *Samsung*, *LG* and *Philips*, are concentrating mainly on smart home environments. Moreover, there are other sectoral companies like *Medissimo*, *Grand Care System* and *Nonin* that are investing their resources in the mobile health care sector.

This panorama, still very heterogeneous and messy, is playing as an inhibitor to the mass-market diffusion that, on the contrary, asks for clear use-cases, ease of use and low price devices and solutions. Therefore, all these new areas suffer from youth's problems and have evident difficulties to establish on large-scale market. On the contrary, the smartphones market continues to dominate the scene, thus all the developers and creators of these new services and technologies are working hard to have a close interaction with the smartphone's world but, each of them, proposes proprietary solutions to specific fields causing the lack of a comprehensive strategy. Since smartphones are increasingly present in people's pockets and home and, in many cases, they are already equipped with several radio interfaces to communicate with different devices, they are becoming the ideal candidates to collect, process and forward data coming from the body and the surrounding environment of each user throughout wireless sensor Networks (WSNs)[1], [2].

Actually, WSNs have been already used in different research fields to collect sensed data in both building environments [3] and healthcare scenarios [4]. For example in [5], WSN nodes have been used to monitor several ambient parameters in conference rooms in order to detect if meetings are ongoing or there are wastes of energy in conference rooms; in [6] networked nodes detect occupancy, ambient light and the state of the lighting system in some rooms of a building to infer potential wastes of energy on the usage of the lighting system. Regarding the healthcare context, a recent review paper [7] summarized clinical applications of wearable technology in the general field of rehabilitation by including health and wellness, safety, home rehabilitation, assessment of treatment efficacy and early detection of disorders whilst in [8] the authors presented the use of WSN technologies for rehabilitation supervision with a focus on key scientific and technical challenges that have been solved as well as interdisciplinary challenges that are still open.

All the communication architectures exploited into the cited works have the main drawback of being specifically designed for a single radio communication interface by not considering the potential of a multi interface approach; on the contrary, our work aims at providing a contribution in this direction, exploring the possibility of creating a smartphone-centric framework that is able to put some order in the current panorama following a simple paradigm: *"my world in my pocket"*. Thus, we propose an architecture that is able to interact with all major today's technologies and that is enough flexible to host the technological advances that will come.

Achieving this goal is not so easy because today there are some technological issues very difficult to assess but, in the coming years, they will surely be overcome. Today's smartphones have, for sure, a set of potentialities to support the "*my world in my pocket*" paradigm; they are always interconnected, they host sophisticated operative systems (*e.g.* Android, iOS) and they have many connection interfaces (*e.g.* LTE, Wi-Fi, NFC, Bluetooth). On the flip-side, smartphones need to overcome some critical obstacles like limited computation, memory and battery capacities. Just think about that: the contemporary use of multiple communication interfaces, inexorably compromises the battery life.

3. INTEGRATED COMMUNICATION

This section presents the main proposal of this work consisting into the design of ($Multi\ SITCOM$), a unified communication framework able to support multi standard, multi interface and multi technology communications by following a specific Smartphone-centric approach. According to this vision, we first provide a high level description of the proposed integrated framework and then we further detailing some important implementation aspects.

3.1 System Architecture

In particular the figure 1 shows a future communication scenario in which the widely available and powerful smartphones, already present on the market, can play a vital role in our daily life helping us in different situations. The proposed smartphone-centric architecture can use different communication technologies to interact with several human contexts by communicating and acquiring data from medical devices, lifestyle and environmental sensors. These data can be sent later to experts in the specific field such as doctors, nutritionists, personal trainers and emergency teams in order to constantly monitor the user behaviors with the aim of correcting wrong lifestyles or promptly offering help in critical situations. The main challenge of this communication architecture is, for sure, the seamless integration of such variegate communication standards, already supported by different devices specifically designed for precise purposes at different times. For example, by focusing on the communication technology, most of recent medical devices supports the ANT+ [9] standard; lifestyle sensors are mostly based on Bluetooth SMART [10] and NFC [11] whilst the environmental sensors, whose technology is less recent than the other ones, make use of ZigBee [12] high level communication protocol based on the IEEE 802.15.4 standard. The integration and harmonization of the plethora of such dissimilar communication protocols and standards represents

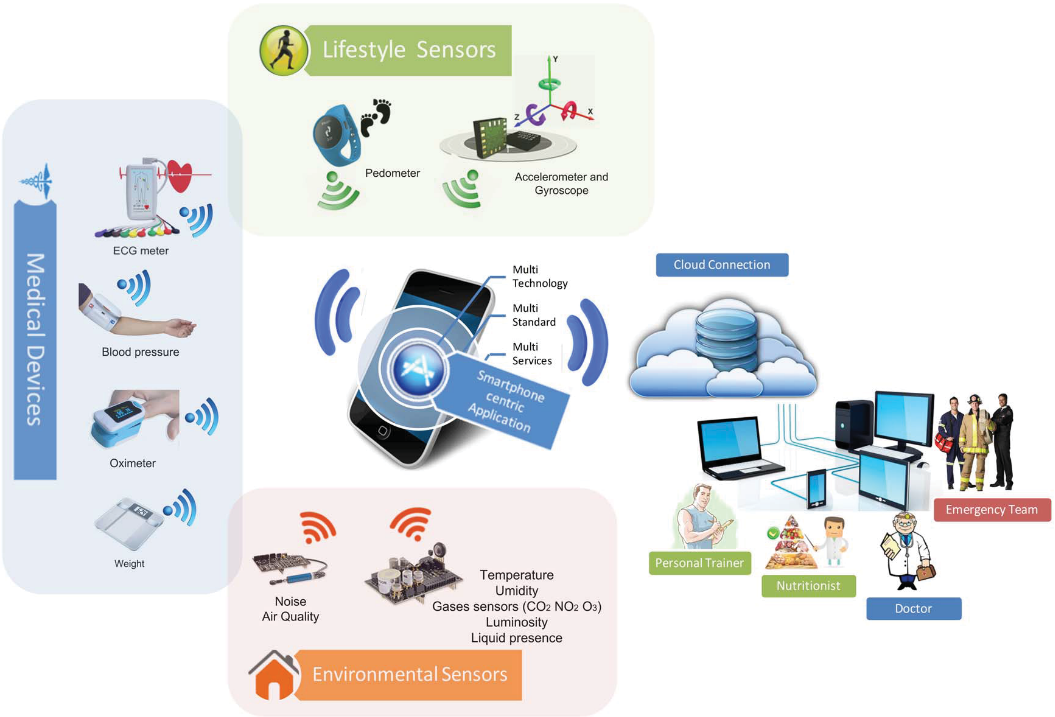

Figure 1: General communication architecture.

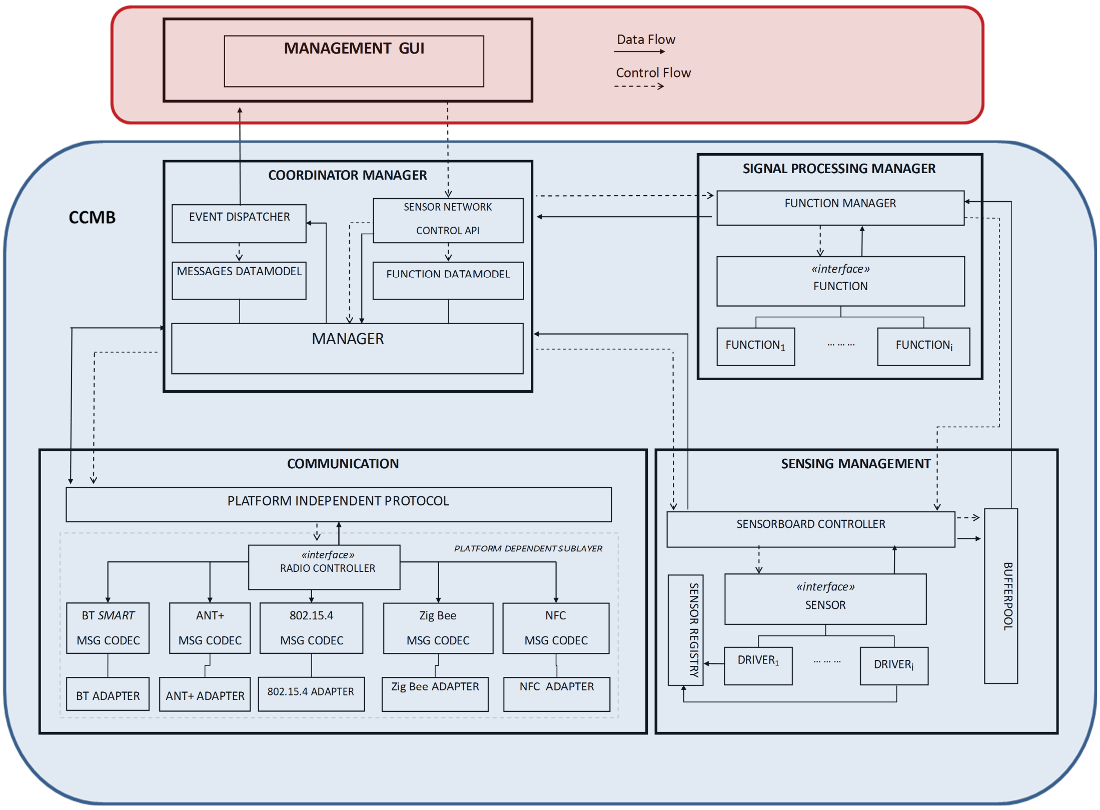

Figure 2: Software architecture of the smartphone centric application.

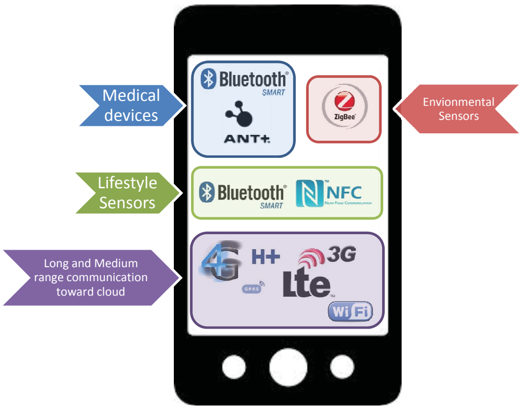

Figure 3: Communication interfaces supported by the smartphone centric application.

the main issue to be addressed in order to really take advantages from the potential offered by modern smartphones equipped with multiple interfaces (see figure 3).

3.2 Software Architecture

In this section we describe the software architecture of the smartphone centric application that is mainly composed by a *Management GUI* through which the user can receive notifications coming from remote sensors also performing a number of settings on individual sensor devices and a CCMB *(Communication Control and Management Brain)* able to acquire and analyze data from different interfaces in order to detect anomalous situations. In particular the CCMB module is composed of four main logical blocks that can interact with each other as shown in Figure 2:

- The *Communication* block handles the reception and transmission of messages over the air, and manages the radio duty cycling. It is composed of a series of decoders for incoming packets and a series of encoders for outgoing packets. Each message received or sent is initially handled by the radio controller that provides a common interface on a specific radio adapter that can be dynamically loaded to support several communication technologies such as Bluetooth SMART, ZigBee, NFC ecc.

- The *Sensing Management* block acts as an interface to the sensor devices by creating periodic timers when the remote sensing operation is required by a specific user, or it may simply take a reading on the sensor devices. The controller within this block can handle a variety of sensors regardless of their hardware specifications through the appropriate interfaces. This ensures modularity and efficiency. The controller also uses a BufferPool to store the readings that become available for the signal block processing. Going into detail, the BufferPool consists of a set of circular buffers and provides two mechanisms for information access; *i)* upon request, by using specific getting functions for information retrieving; *ii)* by using listeners to get notification when new information from the sensor devices are available. Finally the Sensor Registry contains a list of each active device to connect to in order to receive information.

- The *Signal Processing* block uses a function manager module to manage a flexible, customizable and expandable feature set of signal processing operations, such as mathematical functions, filters, alerts based on thresholds that can be applied to any stream of information coming from the sensors. Within this module, it is possible to develop the intelligence able to make the smartphone even more smart in order to detect anomalous situations.

- The *Coordinator Manager* block, which derives from [13], is in charge for the management of the interaction between the sensing, signal processing and communication modules; moreover, it includes a check on the features that can be used by the network of sensors and an event dispatcher. The first is an interface available to the developer, through which it runs the underlying BSN (for example, activating the sampling of a sensor or the signal processing) and the second is concerned to forward events such as the discovery of new nodes, alarms or user messages.

4. TESTBED IMPLEMENTATION

In this section we describe the testbed implemented to measure the performances of the proposed smartphone centric application with the aim of validating the overall system architecture. We have deliberately chosen to reproduce a standard average user scenario. In fact, the testbed has been conducted by using a *Samsung S3* smartphone which does not represent the cutting edge in the mobile phones market and neither has any specific add-ons, so that it can be considered as representative of a wide range of today common user devices and customers.

We developed an *App* based on Android OS able to activate all the communication interfaces available on common smartphones in order to collect data coming from different medical, lifestyle and environmental sensors as shown in Figure 4. In particular, since smartphones available on the market are devoid of ZigBee radio interface, we integrated a *Micro SD ZigBee* card [14] into a common Smartphone in order to add a new radio interface well suited for the communication with environmental sensors such as the widely used *Waspmotes* [15]; furthermore, the smartphone can also collect data coming from environmental sensors throughout the standard Wi-Fi interface by using a MeshLium gateway [16] acting as a bridge between different radio technologies (*i.e.* Wi-Fi and ZigBee). Finally, biomedical and lifestyle data can be acquired by setting the communication on the standard bluetooth radio interface to exchange data with common *Waspmote* sensors or, integrating the *SPINE-android* framework [17] within the smartphone centric application to communicate with specific *Shimmer* [18] wearable sensors well designed to acquire high quality, biophysical and movement data in real-time. All the data coming from those different interfaces are firstly stored on a local *SQLite DataBase* and then they are sent to a remote server throughout a 3G/4G interface in order to be further processed and made available to different experts in specific fields.

Figure 4: Communication scenario for testing the smartphone centric application.

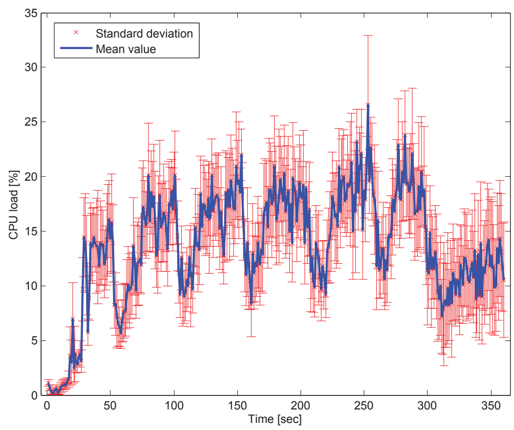

Figure 5: CPU load by activating all the interfaces.

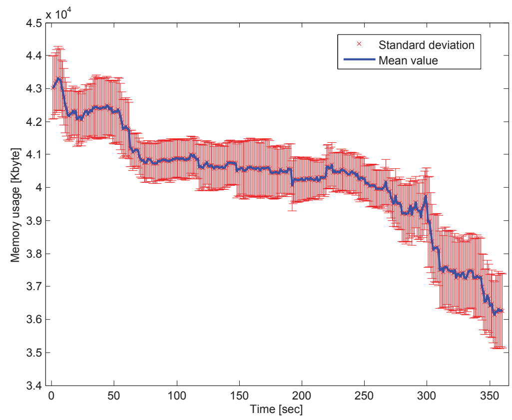

Figure 6: Memory usage by using all the interfaces.

4.1 System performance analysis

The *Multi SITCOM* testbed aims at investigating the potentials of a variegate communication scenario in which the smartphone represents the natural and transparent interface between each user and a more complex services platform. Once designed the smartphone-centric application to support all the communication standards within the presented scenario, we show the smarthphone performances in terms of energy consumption, memory and CPU usage to further discuss about the effective use of such integrated communication architecture.

4.2 Results

During the testbed, the smartphone centric application collects and forwards data received from different sensors on different communication interfaces (*i.e.* see table 1) for several periods, six minutes long; in particular, to better evaluate the system performances, we decided to repeat the test 10 times with the aim of averaging the traffic load distribution due to the natural asynchronous data transmission.

Figure 5 shows that the proposed application has an average CPU load of about 14% and a maximum memory amount of $45MBytes$ is required to make it running even if, this value is progressively reduced by the operating system scheduler as shown in figure 6. Regarding the energy consumption we conducted a 30 minutes long test to make more evident the battery level decrease; in particular the *Samsung S3* smartphone is equipped with a $2100mAh$ battery at $3.8V$ turning into an energy capacity of $7.98Wh$. During the whole testing

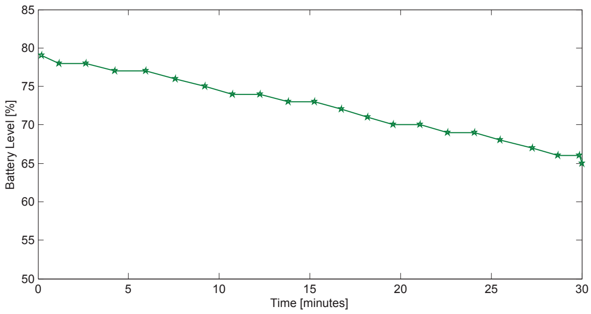

Figure 7: Energy consumption.

Table 1: Sensors connected to the Smartphone-centric application throughout several interfaces.

	Interfaces	
Bluetooth	**SD-Zigbee**	**Wi-Fi**
- 2 WaspMote BT Pro - 2 Shimmer	2 Waspmote XBee ZB-Pro	2 Waspmote XBee ZB-Pro

period, we experienced an energy reduction of about 15% (see figure 7) turning into a smartphone lifetime of more than 3 hours.

5. CONCLUSIONS

In this paper we proposed the (*Multi SITCOM*) framework based on a smartphone-centric application able to continuously collect and forward data coming from wireless sensors transmitting over different communication interfaces and standards. The results, obtained throughout a real testbed on a common smartphone, fully validate the proposed software architecture by demonstrating the ability of acting as a data collector and handler without making an excessive use of resources in terms of CPU and memory. At the same time, the testbed has highlighted the existence of few limitations mostly related to the energy consumption which, realistically, can be overcome quickly by the development of more efficient radio interfaces and batteries. As future works, we planned to extend the testbed to explore today real limits of such communication architecture by increasing the number of sensors and by using cutting edge devices (*i.e.* top level smartphone and tablet) equipped with enhanced radio interfaces (*e.g.* Bluetooth Low Energy, ANT+).

6. ACKNOWLEDGMENTS

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