Dependable Services for Mobile Health Monitoring Systems

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ABSTRACT

The design and realization of health monitoring systems has attracted the interest of large communities both from industry and academia. Remote and continuous monitoring of patient's vital signs is the target of an emerging business market that aims both to improve the quality of life of patients and to reduce costs of national healthcare services. Such applications, however, are particularly critical from the point of view of dependability. This presents the design of a set of services for the assurance of high degrees of dependability to generic mobile health monitoring systems. The design is based on the results of a detailed failure modes and effects analysis (FMEA), conducted to identify the typical dependability threats of health monitoring systems. The FMEA allowed the authors to conceive a set of configurable monitoring services, enriching the system with the ability to detect failures at runtime, and enabling the realization of dependable services for future mobile health monitoring systems.

Keywords: Ambient Intelligence, Dependability, Failure Modes and Effects Analysis (FMEA), Health Monitoring, Patients

1. INTRODUCTION

Health monitoring systems have been shown to be effective in helping to manage chronic disease, post-acute care, and monitoring the safety of the older adult population. They can help older adults slow progression of chronic disease and ensure continued recovery after being discharged from an acute care setting. The implementation of such systems is gaining an increasing attention in the academia and the industry, also due to the increasing healthcare costs and the aging of the world population (Hao et al., 2008).

To this purpose, cabled measurement equipment is already used to guarantee reliable and robust control of vital signs. However such systems complicate patient autonomy and mobility. Hence, wireless technologies and mobile devices are starting to be applied to build more comfortable and patient-friendly health monitoring systems (Paksuniemi et al., 2006).

Nevertheless, the use of wireless technologies and the adoption of commodity hardware/software platforms, such as smartphones, pose new challenges on the correct functioning of
health monitoring systems. Wireless channels can be affected by packet loss, due to shadowing and absence of signal coverage. Smartphones can be subjected to unpredictable failures, which could affect the correct functioning of the system. Finally, cheap and wireless-enabled medical devices can exhibit wrong readings and temporary disconnections from the so-called Body Area Network (BAN) (O’Donovan et al., 2009). These issues may induce the medical staff to take wrong decisions, e.g., to administer wrong dosages of medicine, which can happen to be fatal for the patient.

For these reasons, the problem of failure detection and management in health monitoring systems is starting to be addressed in the literature, especially for mobile systems. However, several studies are based on simplistic failure assumptions or on basic fault-tolerance schemes (such as, sensor redundancy), which are not assured to cover all possible failure scenarios. For instance, sensor replication is ineffective against smartphone failures.

To overcome the limitations of current solutions, in this paper we propose the design of reliable mobile health monitoring system, based on the configurable and the automatic deployment of system monitors, enriching the task of vital sign collection with the ability of detecting failures at runtime, hence enabling the realization of dependable health monitoring services. Differently from the previous attempts in the literature, we base our design on the results of a detailed Failure Mode and Effect Analysis of a typical mobile health monitoring system (Cinque et al., 2011).

The FMEA allowed us to identify the failure modes of the main components composing such systems, by taking advantage of our past experience and detailed field studies on the dependability of mobile devices, wireless communication technologies, such as Bluetooth, and wireless sensor networks (WSNs). The characterization of the failure modes of the system components allowed us to identify the main responsibility of system monitors, along with their placement in a typical mobile health monitoring architecture. The driving idea behind our design is to keep monitors transparent to application developers, allowing them to implement dependable health monitoring applications only by using high-level collection and delivery services. Such services are in turn conceived to exploit the underlying system monitors to detect the failures and potentially react to them. In order to let the solution be adaptable to different application needs, monitors are conceived to be activated and configured automatically, based on a high-level and system-agnostic specification of the desired dependability level.

The rest of the paper is structured as follows. The related work is presented in Section 2; Section 3 describes the typical architecture of a mobile health monitoring system, while in Section 4 we discuss about the results on the realized FMEA. The proposed monitor-based dependable architecture is presented in Section 5. Finally, Section 6 reports our concluding remarks.

2. RELATED RESEARCH

Currently, the research is progressively recognizing the need of novel solutions to build dependable health monitoring systems. These solutions mainly focus on two key issues: node failures and wireless network interference.

Regarding node failures, the power consumption of battery driven devices represent a remarkable issue, which is a limiting factor for long-term monitoring. Although the emerging of new technologies (Kansal et al., 2007) and new standards like the bluetooth low-energy profile, this issue cannot be considered definitively solved (Zhang et al., 2009). For this reason, the system must be able to detect low battery levels and to migrate onto spare devices.

In addition, both WSNs and BANs may suffer from intentional or unintentional node removal or unresponsive nodes. While in WSNs, this issue can be resolved with new path discovery or redundant paths, in BANs this may cause the loss of important vital signs being monitored by the failing sensor. A combination of node redundancy and multi-sensor data fusion
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