Dependability of Body Area Wireless Sensor Networks in Assistive Care Loop Framework

By

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CERTIFICATE OF AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Date:

02-NOV-2012

In the memory of my beloved *Balu Appa*

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List of Award and Publications

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Journal

- **V. Balasubramanian**, and D. B. Hoang, "Reliability Measure Model for Assistive Care Loop Framework using Wireless Sensor Networks." *International Journal of Healthcare Engineering*, vol. 1, no.2, pp. 239–254, 2010.

- C.S Homer, C.J. Catling-Paull, D. Sinclair, N. Ahmad, **V. Balasubramanian**, M. Foureur, D.B. Hoang and E.M. Lawrence, "Developing an interactive electronic maternity record", *British Journal of Midwifery*, vol. 18, no. 6, pp. 384–389, 2010.

Conference Proceedings

- **V. Balasubramanian**, T. A. Zia and Doan. B. Hoang, "Addressing the Confidentiality and Integrity of Assistive Care Loop Framework using Wireless Sensor Networks", in *Proceedings of the 21st International Conference on System Engineering*, Las Vegas, NV, USA, 2011, pp. 416-421.

- **V. Balasubramanian**, and D. B. Hoang, "Availability Measure Model for Assistive Care Loop Framework using Wireless Sensor Networks", in *Proceedings of the 6th International Conference on Intelligent Sensors, Sensor Networks and Information Processing*, Brisbane, Australia, 2010, pp. 281-286.

- **V. Balasubramanian** and D. B. Hoang, "SOAP-based Assistive Care Loop using Wireless Sensor Networks", in *Proceedings of the 1st IEEE International*

Symposium on IT in Medicine and Education, IEEE Computer Society, Xiamen, China, 2008, pp. 409–414.

- D.B. Hoang, E.M. Lawrence, N. Ahmad, **V. Balasubramanian**, C.S. Homer, M. Foureur, and N. Leap, "Assistive Care Loop with Electronic Maternity Records", in *Proceedings of the 10th IEEE International Conference on e-Health Networking, Applications and Services*, Singapore, 2008, pp. 118–123.

- **V. Balasubramanian** and S. Murugesan, "Adaptation of Web Pages for Hand-held Devices," in *Proceedings of the 5th International Conference on Web Engineering*, LNCS Springer, Sydney, Australia, 2005, pp. 435–440.

- S. Murugesan and **V. Balasubramanian**, "Addressing the Challenges of Web Applications on Mobile Handheld Devices," in *Proceedings of the 4th International Conference on Mobile Business*, IEEE Computer Society, Sydney, Australia, 2005, pp. 199–205.

Abstract

The exponential growth in wireless communication and micro-electro-mechanical systems gave birth to low power, low cost, multifunctional and miniature wireless sensors. Wireless sensor networks (WSNs) are finding applications in many areas, particularly in healthcare, a WSN can be used highly effectively in the form of a Body Area Wireless Sensor Network (BAWSN), to enhance the quality of the contemporary healthcare services. This tendency triggered the in-house healthcare monitoring application (HMA) with the BAWSN as their monitoring component. The quality of life of the patients can be improved with the deployment of a BAWSN because the patients and the care staff would be able to monitor the health condition, to access the electronic medical records and communicate with each other by using a Personal Digital Assistant (PDA) or smart phone in their hands, regardless of where they are located or what their duties might be. This remote monitoring and consultations might reduce the traditional stressful and costly exercise of frequent hospitalisation.

The rising costs of healthcare in many developed countries have influenced the introduction of the HMA into existing healthcare practices. However, the successful deployment of the civilian and commercial HMA is still in its infancy stages for some of the following reasons: (a) a generic framework for building the HMA is needed for the application developer to materialise the concepts, (b) an effective set of measurable properties is required for the users to evaluate the performance of the BAWSN used in the HMA, (c) the method used for measuring the performance of a monitoring application is not suitable for the BAWSN used in the HMA, (d) any unauthorized modifications to health data may induce a false diagnosis and put a life in danger; this must be considered together with the privacy of the users in the application, without any compromise and, (e) the body sensors operate in close proximity to the human body, therefore it is imperative to ensure the operational safety of BAWSN.

Our research shows that the dependable properties of an application encompass most of the essential demands for the actual realization of the HMA. It also shows

that the dependable system can deliver services that can be justifiably trusted. The focus of this work is on the BAWSN, because the service ability of the HMA depends heavily on its monitoring component, the BAWSN. Therefore, in this thesis, we define and investigate six fundamental effective properties, maintainability, reliability, availability, confidentiality, integrity and safety, based on BAWSN requirements under the dependability framework. We built an Assistive Care Loop Framework (ACLF), a maintainable BAWSN-based HMA, for monitoring pregnant women based on an event-driven architecture that follows layered functionalities. A novel critical time parameter is introduced to satisfy the needs of the medical diagnoses that require the BAWSN to rely on the collection of data within a critical time from all of the source sensor nodes. The process and issues involved in the medical diagnoses are also explored; these influenced the characterization of the BAWSN as a time critical application. Based on the critical time, we derived non-device-centric time-specific parameters with which we formulated a novel empirical measure model for the transmission reliability and availability in the BAWSN. To compare the empirical measure model, analogous theoretical models are also derived for the BAWSN's reliability and availability. To safeguard the patient's health data and also to ensure their privacy in the BAWSN, we proposed a secure adaptive triple-key scheme (αTKS) in such a way that it incurs minimal overheads while meeting the stringent time requirements of the BAWSN.

The deployed ACLF exemplifies the concept of the HMA being used not only for alerting the care staff in case of emergency, but also for analysing a patient's progress over a period of time to *forecast* any emergency situation. The performance of the proposed measure models and the implemented αTKS from our real-time test-bed would enable the application developer to measure the performance of the BAWSN-based application because, to the best of our knowledge, no measure exists in the literature as such for a BAWSN-based application. The formulated minimal set of dependable properties might serve as a *benchmark* for evaluating the performance of a BAWSN, and in turn, the HMA.

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