FRAMEWORK FOR QOS PERFORMANCE ASSESSMENT ON BIOMEDICAL WIRELESS SENSOR NETWORKS

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Abstract: A Biomedical Wireless Sensor Network (BWSN) is a special Wireless Sensor Network (WSN) with a small number of nodes designed for medical applications. These networks must ensure that medical data is delivered reliably and efficiently, in order to fulfil a set of pre-established Quality of Service (QoS) requirements. In this way, the research community have been proposing new solutions to improve QoS in WSN, namely in routing protocols and power consumption efficiency. However, there still a need for appropriate QoS guaranties in BWSN. In this paper, possible QoS requirements of BWSN are discussed, together with a framework to automatically evaluate the performance of such QoS techniques. That framework was used together with simulators and operating systems appropriate for WSN, *COOJA* and *Contiki OS*, and proved to be a valuable tool for a proper evaluation of QoS parameters and metrics.

1 INTRODUCTION

The fast development of low-power wireless communication technologies and devices enable the application of WSN in several areas, e.g, ambient monitoring, catastrophe response, industrial and home automation, or healthcare services (Hof, 2007). Regarding the healthcare application of WSN, BWSN can be used to develop new applications and services in different scenarios (see figure 1), e.g., ambient assisted living (AAL), emergency response or patient monitoring (Ren et al., 2005). In any of these scenarios, BWSN are presented as a key technology to ensure high quality levels in the healthcare services that are provided to citizens. However, since such networks support some degree of medical care, they must guarantee appropriated levels of QoS, namely with respect to the intrinsic characteristics of medical data and their applications (Abreu et al., 2011). Then, the study of QoS in BWSN emerges as a very important area of research, being a very challenging task due to the interaction of the different phases of hardware and/or software development (Bhuyan, 2010).

Software development and debugging on BWSN is morose and difficult work to carry out, with many interactions and testing phases

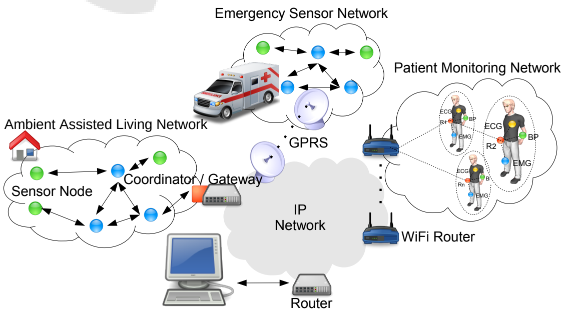

Figure 1: BWSN applied to different healthcare scenarios: ambient assisted living (AAL), emergence response and patient monitoring.

(Huber et al., 2011). Performance evaluation of the different QoS parameters requires comparing different implementations and, based on data retrieved from tests, verify which proves to be the best implementation. To address this issue, a platform-independent framework was designed and implemented to evaluate the QoS and performance of BWSN. This framework can be used for simulated or real networks and, thus, be used to help in the initial phase of applications development, as well as at later design stages, to evaluate real scenario implementations.

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First, the QoS requirements are briefly discussed, as well as the parameters and metrics of BWSN. Then, the framework that automatically evaluates the performance of QoS techniques applied to BWSN is presented.

2 QOS REQUIREMENTS OF BWSN

As discussed in (Gama et al., 2007) and (Abreu et al., 2011), BWSN need to ensure an appropriate level of QoS. The QoS requirements of BWSN are imposed to the network and depend on the target applications. They don't depend only on the intrinsic characteristics of data to be transmitted, but also on its purpose.

According to (Ruiz, 2006) and (Marchese, 2007), from the network point of view, the most important parameters used to measure and ensure the QoS required for a given application, in traditional IP networks for telemedicine applications and services, are presented in table 1.

Table 1: QoS parameters, to traditional IP networks, concerning the network point of view.

PTD	Packet Transfer Delay
PDV	Packet Delay Variation
PLR	Packet Loss Ratio
PER	Packet Error Ratio
BW	Bandwidth

However, in the context of WSN, due to its unique characteristics such as: extremely low resources (memory and computational power) constrained nodes or limited radio capabilities and battery, the QoS parameters presented earlier are insufficient. In (Chen and Varshney, 2004) the authors identify new QoS parameters, presented in table 2, that reflect the collective effort of all network nodes to perform a given task.

Table 2: Collective QoS parameters to WSN concerning the network point of view.

CPTD	Collective Packet Transfer Delay
CPLR	Collective Packet Loss Ratio
CDR	Collective Data Rate
IT	Information Throughput

BWSN can be used to support several healthcare applications and services. Therefore, they have to provide QoS support to multi-applications. Concerning, the application point of view, there are different QoS requirements that must be satisfied. However, despite the different specifications, it is possible to identify some requirements that are common to most applications or services.

Below, those requirements are identified and their relevancy and applicability will be briefly discussed.

The authors of (Xie and Wang, 2010) identified some important application-centric QoS requirements that can be applied also to BWSN. Below, those requirements are identified, and their relevance and applicability will be outlined.

Ability to Provide Valid Data, in BWSN the data integrity is a major requirement. The decisions made by healthcare providers depend on the data provided by the network. In this way, this is a requirement that must be satisfied on all BWSN applications and services. This parameter is influenced by topology, coverage and traffic capacity, connectivity, and energy consumption;

Delay Management, the time spent to transmit data and detect events is a very important issue in BWSN. Different applications have distinct delay requirements, however, all of them have some limit that must be respected. This is a requirement that must be applied with different weights to different applications. This parameter is affected by collective packet transfer delay, information throughput, network topology and decision algorithm;

Network Lifetime, is the period of effective service. This is a major issue especially in implanted BWSN nodes. It is affected by network topology, connectivity and energy consumption;

Network Survivability, is the ability to automatically restore. It is more evident in BWSN with mobile nodes or in scenarios with constant changes, like in a hospital where patients are being monitored. It depends on deploying density of nodes and routing protocols;

Decision Accuracy, the quality of the decision made by healthcare providers depend on the quality of the data collected, transmission delay and decision algorithm.

Developing QoS mechanisms to guarantee appropriate levels of QoS is important but not sufficient (Asokan, 2010). To prevent QoS degradation, due to network limited capacity, it is necessary to develop tools to supervise and manage the network. This work contributes, with the development of a framework, to help in the development and evaluation of strategies to supervise and manage the QoS on BWSN.

3 QOS ASSESSMENT FRAMEWORK FOR BWSN

As discussed previously, BWSN have to fulfil strong QoS requirements each of which have to be systematically tested to guarantee high levels of confidence and reliability. This is true, not only in research, but also during the development of specific applications. BWSN have to pass very demanding tests to be accepted by its users and the healthcare providers. They have to be tested in both simulated and real scenarios.

The development of applications and protocols for BWSN is a challenging, time consuming and error prone task (Mozumdar et al., 2010). To avoid this situation various software and hardware tools have been developed in the last few years (Huber et al., 2011).

The use of simulators for BWSN software development proved to be a great help, and with widespread use within the academic and industrial community (Liang, 2009). However, the raw data generated by simulators needs to be analysed in order to extract results, as well as for reporting purposes. This analysis may be laborious and time consuming. In fact, the data analysis and report generation is one of the bottlenecks of software development processes. To mitigate this problem, a framework was developed, based on open source tools, for automatic data analysis and QoS performance assessment.

The developed QoS assessment framework is platform-independent and might be used both for simulated and real networks. In this way, it's possible to evaluate the network along the development process as well as when the network is finally deployed in a real application. This is an important feature because it enables easier performance comparison between simulated and real BWSN.

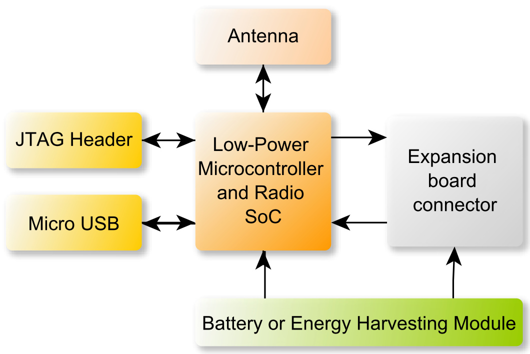

Figure 2: WSN hardware platform architecture.

In order to implement the real BWSN, a hardware platform (WSN mote) was developed and included on the QoS assessment framework. The mote was developed to be modular, thus, it can be used in several scenarios. Its functionalities can be extended via daughter boards, providing different sensing capabilities. Depending on the daughter sensor board, the mote can be used in different healthcare applications. Figures 2 and 3 show its architecture and implementation, respectively.

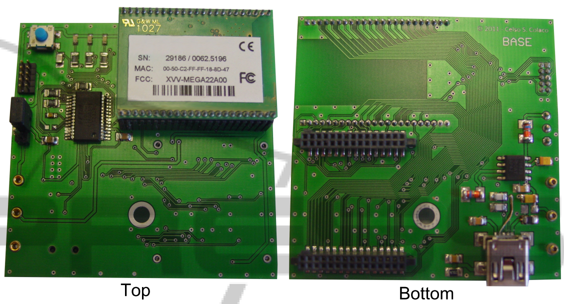

Figure 3: WSN hardware platform implementation.

The core element of the mote is the low-power RF module deRFmega128. This module is a 2.4 GHz radio transceiver and a 8Bit microcontroller single chip solution (SoC) (Dresden, 2011). To interact with the outside, the mote contains three interfaces: 1) a JTAG interface to program and debugging purposes; 2) a mini USB port; 3) a 60-Pin header to connect to daughter sensor boards. The mote power supply can be from different sources, e.g: battery, USB port or energy harvesting modules.

3.1 Framework Architecture

The QoS assessment framework follows a two layer architecture: Data Analysis (DA) and visualisation, as can be seen in figure 4. The DA layer is responsible for results extraction from raw data, generated by simulated or real networks, and these will be represented in such a way that will be easily interpreted. The visualisation layer is used for report generation purposes.

The software used to extract results from raw data and the report template depends on the study that is being carried out. However, once developed, the software can be reused in future assessments. The results representation and report generation software is independent of the application. In this way, the network QoS evaluation is improved between different tests of the same study.

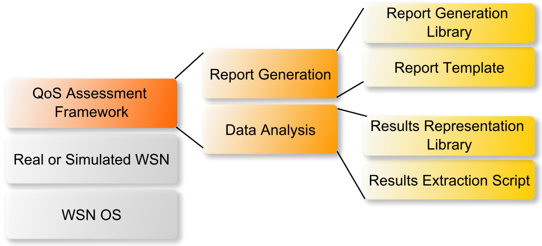

Figure 4: QoS assessment framework architecture.

3.2 Framework Evaluation

To evaluate the implementation of the QoS assessment framework, a BWSN case study was defined for simulation. The BWSN was simulated using *COOJA* that, with *Contiki Operating System* (*Contiki OS*), can be considered a complete development platform for WSN. *COOJA* allows simultaneous simulations at different levels, namely: application, network, operating system and machine code instruction level (Osterlind et al., 2006) (Dunkels et al., 2004). One of the major advantages in using *Contiki OS* and *COOJA* is the code reuse and hardware platform independence. It is possible to develop the application software and then use it in different hardware platforms, as well as inside the *COOJA* simulator.

There are several applications to BWSN. However, in this case study, the focus is on the monitoring of vital and biological signals, such as, electrocardiogram (ECG), electroencephalogram (EEG), blood pressure (BP) and temperature (T). According to (Ruiz, 2006) and (Varshney, 2009), the default value for the PTD in real-time telemedicine applications and services is 400ms. In this context, the case study aims to evaluate the end-to-end PTD regarding the number of hops in the network and which must be less than 400*ms*.

Each case study consists in: a scenario to deploy the network; a real or simulated WSN; a test script to extract data from the network; a script to extract results from data generated by network; and a report template to easily evaluate the results (see figure 5).

After the establishment of the scenario in which the BWSN will be used, the application is developed on the *Contiki OS* and, then, compiled to the hardware in use. The simulations are performed on *COOJA*. At the end of all the simulations, the generated raw data is analysed and the results extracted. Finally, a report is generated to present the results and compare them with the previous. Figure 5 illustrates the framework operation.

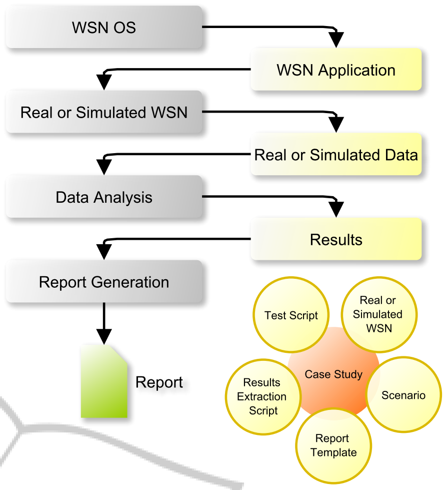

Figure 5: QoS assessment framework operation.

To study the end-to-end delay of a package regarding the number of hops in the network, 9 simulations were mounted in *COOJA* (1 to 10 hops). Figure 6 represents the simulation scenario to measure the end-to-end delay in the case of 5 hops. The data from each simulation were extracted with a script written in *java script* using the *Contiki Test Editor* plugin of *COOJA*.

The extraction of results from data generated by simulation was done through a script that uses the Linux Shell Scripting capabilities. To represent the results, the *Gnuplot* graphing utility was used, and the report was automatically generated using the *pdflatex* library.

To perform the simulations experience, *COOJA* was used in batch mode, which made it possible to automatically perform all the simulations and carry out the results, see figure 6.

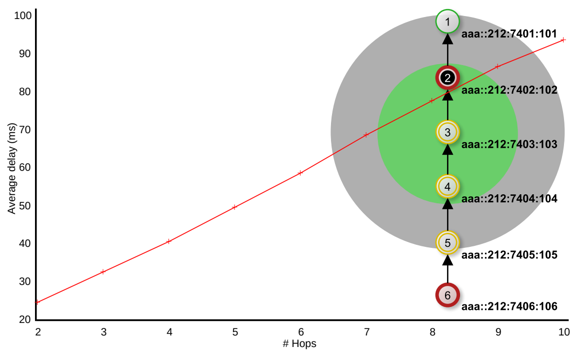

Figure 6: Mean end-to-end delay of a package regarding the number of hops in the network.

As shown in figure 6, in this test case scenario, the end-to-end PTD is less than 400ms. However, if necessary, it is possible to adjust the software, and automatically perform new evaluations without human interaction streamlining the process of software development.

4 CONCLUSIONS

This work presents a framework to support the software development for WSN that was developed envisioning QoS deployment and evaluation of BWSN. It has proved to be a very useful and complementary tool for WSN simulators and operating systems. As a following step, this framework will be used as a tool to evaluate and test protocols, targeting QoS requirements of BWSN, exploring the best solutions to achieve the QoS parameters presented in tables 1 and 2 in simulated and real BWSN. As it allows a straightforward network deployment after simulations, this framework has the potential to reduce the debugging time after a real network deployment.

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