Guidelines and Challenges Towards the Implementation of Intelligent Sensing Techniques in a Water Quality Prediction Application

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Abstract: SmartCoasts is an INTERREG 4A project aimed at providing novel solutions for real-time monitoring and forecasting of coastal water quality. The intended predictive system relies on freely available online weather forecasts and a suite of real-time meteorological data measured across a river catchment. In a preliminary stage, a prototype has been developed taking the real-time data from GPRS loggers deployed at strategically located stations according to a centralised architecture. Even though such system has proven its suitability providing accurate predictions, certain pitfalls that hamper usability have been detected. Adding intelligent capabilities to the sensing nodes might help to overcome such situation. This paper presents a general overview of the current situation and discusses some of the major challenges and difficulties that need to be faced in order to set up a really smart Environmental Wireless Sensor Network.

1 INTRODUCTION

For more than a decade, Wireless Sensor Networks (WSNs) have been widely adopted both in indoor and outdoor monitoring applications. While indoor locations are usually less exposed to external interferences and weather hazards, which eases durability, maintenance and repeatability of the underlying hardware and software, outdoor applications are more prone to be affected by the surrounding conditions. Nevetherless, applications where broad coverage area is a must, such as climate monitoring (Arampatzis et al., 2005), water quality monitoring (Le Dinh et al., 2007) and precision agriculture (Hwang et al., 2010), to cite some, are becoming nowadays increasingly popular.

The initial achievements in deploying Environmental Wireless Sensor Networks (EWSNs) as a reliable solution for data collection and observation were mostly based on centralised architectures where sensor nodes simply act as data collectors and transmitters towards one or more base stations and lack any processing capabilities, as this happens in a single server (Martinez et al., 2004). Such approach is simple and robust, but lacks flexibility on scaling and software upgrading. Moreover, maintenance is complicated due to the remote location of the nodes.

On the other hand, distributed EWSNs are useful in many scenarios, such as water quality monitoring and forecasting, where wide area continuous monitoring and minimum human intervention are required. To achieve such goal, the nodes in the network should collaborate in a self-managed manner, taking autonomous decisions about gathering, processing and transmitting useful data at minimum energy cost.

This paper is a case study on the deployment of an EWSN aimed at feeding a marine water quality forecasting system for short and mid-term predictions. It is our goal to outline the main lessons learnt from the work conducted until now, providing some general ideas that could contribute to enable the reliable implementation of generic environmental monitoring applications. In particular, we consider that upgrading from a centralised architecture, based on stand-alone data loggers, to a distributed one might contribute to improve the general performance of the forecasting system.

The rest of the paper is organised as follows. In Section 2 the currently deployed system and its main components are described. Section 3 identifies the drawbacks which we faced during the exploitation of SmartCoasts, while Section 4 introduces the proposed solutions, finishing with the conclusions in Section 5.

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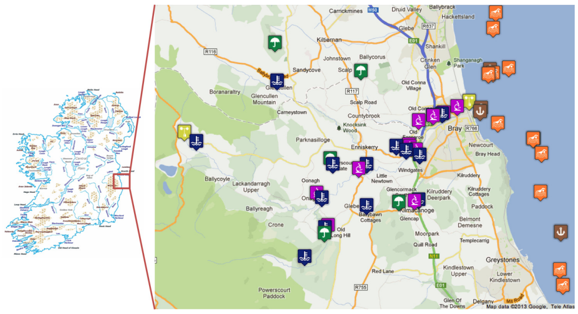

Figure 1: SmartCoasts deployment area map. Measurement locations: - River level; - Weather station; - Rain gauge; - Microbial sampling; - ADCP buoy; - Water quality validation point.

2 GENERAL OVERVIEW OF THE SMARTCOASTS PROJECT

Smart Coasts (SCs) (SmartCoasts, 2013) is an Irish and Welsh INTERREG 4A project broadly motivated by the EU Bathing Water Directive, which encourages the development of information and communications technology (ICT) tools and real-time public information systems in order to improve the maintenance of public health and increase the number of beaches passing the new EU standards, thus qualifying for awards such as the Blue Flag. SCs is currently being validated in the Bray Bay (Ireland), and across the catchment of the local River Dargle. Figure 1 shows a map of the area under study.

The development of a water quality monitoring and prediction framework as the one described here leans on contributions coming from a wide spectrum of research fields, such as Microbiology, Civil Engineering, Computer Science and Telecommunications. This is an implicit consequence of the holistic approach followed in the SCs project. Thus, a rich variety of sources act as system inputs, as Figure 1 suggests. The core of the marine water quality forecasting system comprises, on the one hand, an integrated catchment-coastal model to simulate flow and contaminant transport from the Dargle to the coast, and on the other, a database that provides a simple way to access and manage the large amounts of input and output data required and generated by the system –a detailed description of both components and the system inputs can be found in (Bedri et al., 2013)–. Figure 2 traces out the architecture of the described system as well as all the data flows involved.

2.1 Main Features of the Deployed Network Nodes

The primary meteorological phenomenon driving the integrated model is forecasted rainfall, which is amended by real-time observations when a significant deviation is detected. In-field data across the catchment are collected by commercial data loggers developed by Isodaq, known as Frogs (IsodaqFrog, 2013) (see Figure 4). These devices run on an 8-bit microcontroller and are equipped with a GSM/GPRS modem, which can be connected to an internal or external antenna. Several digital, analogue (16-bit A/D) and SDI-12 sensor inputs are provided.

A battery life of up to 7 years is possible but, under the current configuration –the Frogs are transmitting the collected data on a daily basis–, the estimation is reduced to two years. This figure will be dramatically reduced should the sampling rate be increased, as desired for example when big rainfall events occur. In such situations, the integrated model should get updates every 15 minutes, which would drop battery life expectancy to only 3 months if the Frogs would keep working continuously at this rate.

3 DRAWBACKS REVEALED BY THE CURRENT NETWORK IMPLEMENTATION

The network currently in operation cannot be actually considered an EWSN, since the Frogs do not interact with each other and follow a point-to-point communication schema through a GPRS base station, thus completely relying on the public data network infrastructure. Such approach has demonstrated its validity within the scope of the research work described here, but also unveils a number of weaknesses.

First of all, some of the course sections of the River Dargle and its tributaries are located in dark or marginal areas where the GSM/GPRS signal coverage is precarious, as Figures 3 illustrate. This has strongly conditioned the final location of the Frog data loggers, as not the most suitable places in terms of data relevance have been chosen, but those as close as possible where the base station was reachable. Moreover, signal fading events, unpredictable in the radio propagation study made during the design phase of the project, have been sporadically experienced as a consequence of the changing surrounding conditions, strongly affecting the radio link reliability.

Secondly, since the density of the deployed loggers is very low and their functionality is restricted

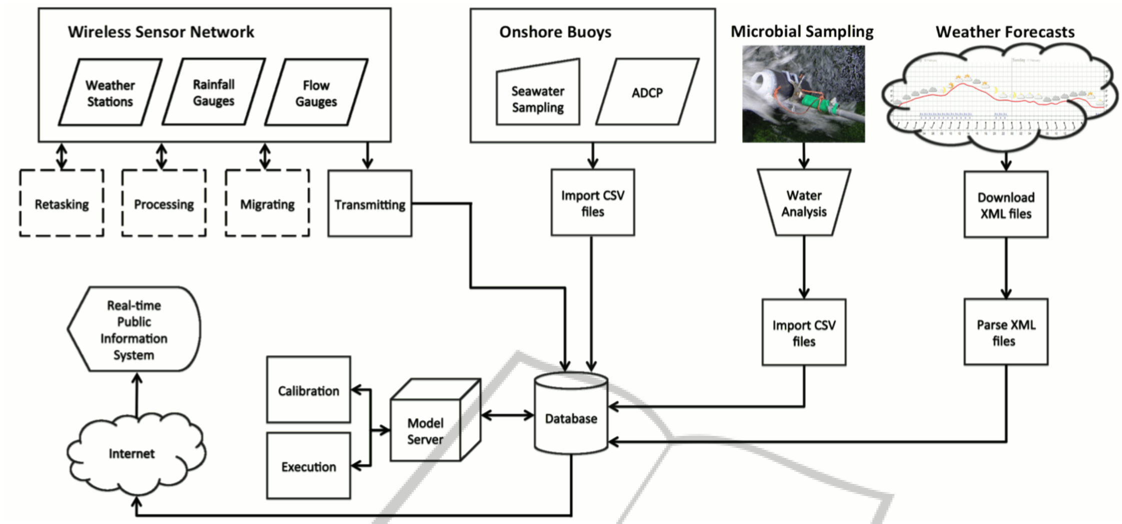

Figure 2: SmartCoasts architecture and data flow schematic.

by the features that the commercial infrastructure offers, the reactivity to the changes in the environment conditions is very limited. This is because the Frogs can only be scheduled to send the collected data on a fixed-period basis. On the contrary, it is desirable that the network initiates a sequence of events, should a certain event exceed a predefined threshold. For example, for the sake of our application, it would be really interesting to increase the sampling rate downstream, when the rainfall at the river spring outnumbers a certain amount, in order to better capture the flow rise and the evolution of the faecal contamination washed off.

Finally, the determinism that the communication scheme shows, allows a quite accurate estimation of the power consumption in the long term, which is definitely a benefit, but on the other hand, provides a suboptimal solution. The lack of processing capabilities in the sensing nodes impedes taking autonomous decisions about who, when and what to transmit, which would improve the energy management and thus, the life expectancy of the network nodes. Given the relatively high costs, both in economic and energy terms, of transmitting to the base station at this stage, it is desirable to enable nodes with short-range communication features when possible, since not always it is necessary to transmit all the collected information to the base station, should that transmission could be delivered to a neighbouring node.

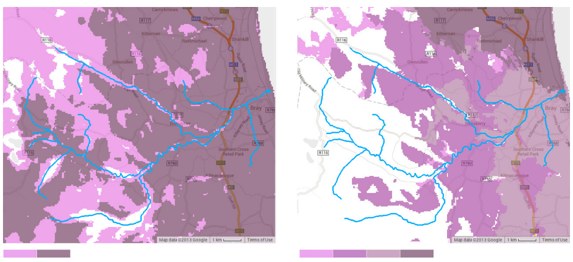

Figure 3: GSM (left) and GPRS (right) signal coverage estimation for the River Dargle catchment area. The colour bars indicate an increasing strength, meaning the left-most colour a poor signal and the right-most one a good signal. No signal areas are represented in white.

4 PROPOSED SOLUTIONS

Until now, our research work has mainly focused on developing a functional prototype that demonstrates the feasibility of the intended water quality forecasting system. This is why most of the attention has been given to the integration aspect, with special focus on data acquisition and management. The next step –currently in progress– is aimed at finding an optimal solution to the trade-off between energy consumption and transmission rate. Some improvements both in the hardware and software levels are proposed.

In the short term, the sensor nodes are being upgraded from an 8- to a 32-bit microcontroller architecture. At this moment we are developing initial lab tests with the ARM-Cortex M3 family, harnessing a SAM3S-EK2 evaluation board (see Figure 4). The newly designed devices offer enough processing power to deal with the computational requirements in the future scenario, where intelligence will be distributed over the entire network, as the nodes are supposed to react immediately when and where an unexpected event happens. That functionality is achieved as a result of implementing the Java ME-based Agent Factory Micro Edition (AFME) agent platform on all

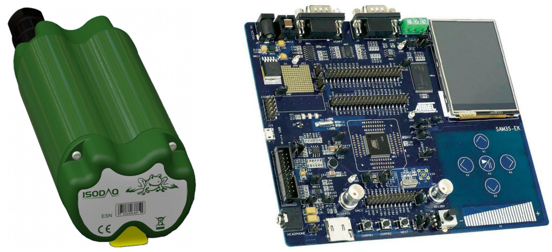

Figure 4: Isodaq's Frog RX data logger (left) and SAM3S-EK2 evaluation board (right).

the network nodes. The final goal behind this decision is maximizing the network life expectancy, as a consequence of diminishing the number and data length of the costly transmissions to the base station, which would be replaced when possible by cheaper short-range communications between the nodes. Besides, enabling the Java technology in the new nodes opens the door to wider interoperable infrastructures that will be able to run the same code on different nature platforms, thus easing environmental data interchange.

Finally, in the long-term it is expected to allow the aggregation of crowdsourced data to the sensed values. With the ubiquitous availability of mobile devices, citizens have turned into a valuable source of environmental data, as suggested by other state-of-the-art research works (CobWeb, 2013). In our opinion, such information would contribute to fill the temporal and spatial gaps that might arise in wide area deployments like this. For instance, an angler by the river could detect a hazardous discharge, take a georeferenced photo and upload it to the system, and this would trigger the network to increase the sampling rate in the area and advice the local authorities to take safety measures. The database-centered approach that has been already followed will facilitate a smooth integration of the crowdsourced inputs, as it works as an abstraction layer that masks the complexity of handling both the data uploaded by the human users and the outputs from the different sensors involved. This is a remarkable feature, given the fact that one of the major bottlenecks in the deployment of environmental monitoring systems is the great number of different proprietary data formats that the sensors can produce. Furthermore, such database will be the core of an environmental information system that will provide short- and mid-term forecasts about the bathing water quality conditions, as well as historical reports delivered in open source formats.

5 CONCLUSIONS

In this paper the case study of a bathing water quality forecasting system based on stand-alone data loggers was presented. We consider the deployed system as a starting point towards the implementation of a fully-featured Environmental Wireless Sensor Network with intelligent data managing and routing.

The main pitfalls encountered until now and the solutions envisaged to overcome those difficulties have been described. In our opinion, the ideas outlined here can benefit several other general-purpose outdoor environment monitoring applications.

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