Poster Abstract: Structural Health Monitoring in an Underground Construction Site: The Roman Experience

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ABSTRACT

This poster presents the work done to monitor the structural health of a Rome B1 underground construction site through a battery-powered Wireless Sensor Network (WSN). We illustrate the specific requirements and challenges of working with wireless sensors underground, and we describe the solutions adopted for obtaining a working WSN that provides a robust solution of on line monitoring. We conclude by presenting an assessment and testing of these solutions, along with the design insights and the lessons we learned during this on-the-field experience.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*

General Terms

Wireless Sensor Networks

Keywords

testbed, structural health monitoring, wireless sensor networks

1. INTRODUCTION

The demonstration of the solutions and the technologies discovered within the European project Genesi [1], concerning hardware and software for "green" monitoring of structural health, has taken place by monitoring a construction site of Rome B1 underground. The actual monitoring took place for a few months, from the end of 2011 to the first half of 2012 using a fully battery-powered Wireless Sensor Network (WSN). The specific goal was that of monitoring the construction of the 700m tunnel connecting the *Conca d'Oro* and *Jonio* new metro stations. The construction involved the use of a 9m diameter Tunnel Boring Machine (TBM) long 70m. The excavation started at the end of November

2011 and finished in mid February 2012. The WSN used for monitoring was made up of 32 wireless nodes, 49 transducers and lasted 4 months. In the remainder of this poster we describe requirements and solutions adopted for the deployment of the WSN, the results we implemented, and the lessons we learned from this on-the-field experience.

2. SCENARIO AND REQUIREMENTS

The monitored tunnel has 4 sections. For each section, 12 vibrating wire strain gauges buried in the concrete blocks of the tunnel were used to measure deformation of the concrete to prevent collapse. Monitoring required 1 sample/sensor/hour, with the real-time transmission of the sensed information to a remote server. In order to obtain real-time reliability, data loss could not exceed 10%, and no more than 3 consecutive packets could be lost per sensor. In addition, to add robustness, 100% of the data read from each strain sensor was expected to be recovered when physically accessing the sensor at the construction site. The monitoring system was expected to be easy to deploy and battery-powered (except for the gateway). The expected lifetime of the monitoring system should exceed one year, with the aim of a final deployment operating for 5.

3. HARDWARE AND SOFTWARE

We deployed a WSN made up of 32 CM5000 wireless motes [2] and an Alix 3D3 embedded system with a 3G USB pen and an UPS backup system for the gateway. One of the 32 wireless motes was acting as a sink for the WSN, 8 sensing motes were interfaced to 6 strain sensors each resulting in 2 motes per monitored section. One mote was sampling temperature and humidity inside the tunnel, and the remaining 22 motes acted as relays to enable wireless connectivity. During tunnel construction the topology kept changing since the motes were placed progressively, as the TBM advanced. The final topology at mid February 2012 is shown in Figure 1. Each mote was housed in an IP55 plastic box. Raytech Magic Rubber [3] was applied over the electronics for protection against the high humidity expected in the tunnel. Relay motes ran on 2xAA Alkaline batteries, providing 3V and 1850mAh. Due to the presence of the additional strain interface, sensing nodes were powered by 2xType D Thionyl Chloride batteries (7.2V, 19Ah).

We used DISSense for data collection [4] on top of the TinyOS 2.1.1 distribution [5]. DISSense is an ultra-low power protocol specifically designed for periodic data collection. It takes advantages of high sampling periods for energy efficiency, and fits well in our scenario, where data are collected
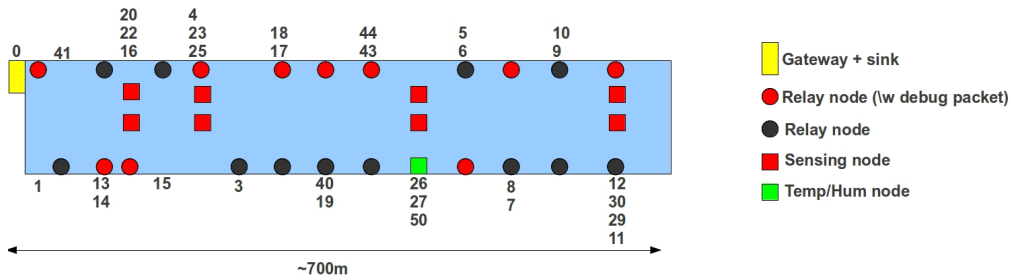
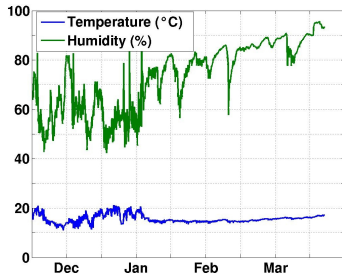**Figure 1: Final WSN topology (February 21 2012).**

Figure 2: Node 50: Temperature and humidity values (December 13 2011 to March 27 2012).

from each sensor once an hour. For this reason, DISSense can feature a very low duty cycle, enabling the WSN to keep running on batteries for years. For debug and statistical purposes, half of the relay nodes also generated packets at the same rate, carrying debug information (Figure 1). DISSense has been extended with additional features for supporting network reboot and local logging. Each mote stores data on a flash eeprom and workers can download the whole eeprom wirelessly by getting close to the mote (single-hop connection). Finally, the gateway has been equipped with auto-starting scripts enabling autonomous recover from power cycles and periodical transfer of the collected data to a remote server.

4. TESTBED RESULTS

The metrics concerned the radio duty-cycle and the Data Delivery Ratio (DDR), namely, the percentage of data packets transmitted by a mote that actually is received by the sink. Results were collected on the topology in Figure 1 from February 22 to March 21 2012. As per the DISSense implementation the radio duty cycle is the same for all the nodes. The observed average duty cycle has been 0.22%, which confirms the effectiveness of such a low-power communication approach for the application requirements. Based on DISSense design, we were expecting high values of DDR for nodes closer to the sink, with a gradual decrease in DDR proportional to the hop distance. Surprisingly enough, while the highest DDR matched our expectations, with 99.9% DDR for node 1, the lowest values have been measured in the middle of the tunnel. In particular node 40 and 44 showed a DDR of 90.8% and 92.5%, respectively. Getting farther in the tunnel, the DDR increased again to 99.1% for node 30. This is because the "quasi linear" topology of our testbed induces a high number of collisions in the middle of the tunnel, due to the hidden terminal problem. Despite data loss, the

values from all nodes and from the temperature and humidity sensor (node 50) were retrieved at the end of the testbed experiments on March 27 2012. The actual values cannot be published due to a required NDA with Roma Metropolitane [6]. Therefore, in Figure 2 we plot the temperature and humidity values sampled by node 50. It is interesting to note the high volatility of the values especially from December to mid January. This is because node 50 was initially installed on the TBM: The sampled values were affected by the activity of the machine. From mid January, when the TBM had almost finished the excavation, we moved the node to its final place, shown in Figure 1.

5. LESSONS LEARNED

The technical solutions we adopted for the testbed were successful, in that everything worked and data conveyed by the network were consistent with those offloaded by the sensors at the end of the testbed experiments. The lessons learned include the following. The UPS and auto-starting scripts of the gateway are critical: we experienced several power failures and, in three circumstances, the power cut was long enough to make the UPS shutdown. In all cases, the system autonomously recovered as soon as the power came back because of the auto-starting scripts. The remote reboot procedure added to DISSense has been extremely useful to recover from a bug that made the network to partition. Finally, as confirmed by the humidity levels shown in Figure 2, protection for electronic is mandatory and the MagicRubber we applied to all the nodes has successfully proven the right tool for the job.

6. ACKNOWLEDGMENTS

7. REFERENCES

[1] Genesi project. http://genesi.di.uniroma1.it
[2] CM5000 Wireless Mote. http://www.advanticsys.com
[3] Raytech Magic Rubber. http://www.raytech.it
[4] U. M. Colesanti, S. Santini, and A. Vitaletti. DISSense: An adaptive ultralow-power communication protocol for wireless sensor networks. Proceedings of DCOSS 2011.
[5] TinyOS. http://www.tinyos.net
[6] RomaMetropolitane. http://www.romametropolitane.it
[7] Treesse Eng. http://www.treesseengineering.com/