Poster Abstract: Bridge structural monitoring through a vibration energy harvesting wireless sensor network

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ABSTRACT

Structural monitoring applications such as corrosion assessment, measurement of concrete temperature or moisture content of critical bridge structures can greatly benefit from the use of wireless sensor networks (WSNs), however energy harvesting for the operation of the network remains a challenge in this setting. We present a multihop vibration-based energy harvesting WSN system for bridge monitoring applications. Our preliminary simulation experiments show that the system is able to maintain energy neutral operation over time, preserving energy with careful management of sleep and communication times.

1. INTRODUCTION

Structural monitoring of buildings, bridges, and other civil structures include the validation of their structural design and their maintenance operation. Deterioration of structural components over time due to aging and environmental influences is a major concern, which could lead to disastrous consequences (e.g., bridge collapses) if not addressed early. Although many studies have shown the effectiveness of wireless sensor networks (WSNs) in structural monitoring applications, the conservation of energy to prolong network lifetime is a crucial aspect that has been stimulating the research in this field for the last decade. While solar and wind power are possible credible alternatives to energy generation, the need for positioning sensor nodes in shaded and sheltered locations (e.g., under a bridge deck) is also often precluding their adoption in real-world deployments.

This work presents the development and preliminary evaluation of a vibration energy harvesting WSN for bridge structural monitoring. Compared with other energy sources (e.g., sunlight), traffic-induced vibrations provide lower performance in terms of harvested power density [2]. This has a major impact on the target class of applications as well as on the design and calibration of the communication protocol for multihop data collection. By combining real acceleration data with an experimentally validated model of a vibration energy harvester, a hardware model, and the COOJA simulator, we conduct realistic and repeatable experiments to evaluate the system in a realistic application scenario.

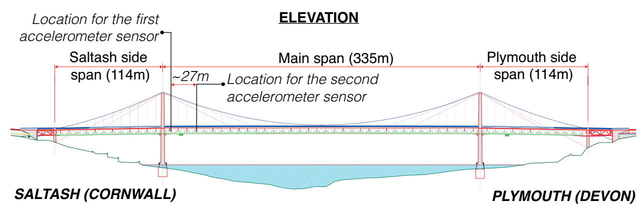

Figure 1: South elevation diagram of Tamar Bridge (UK) showing accelerometer locations.

2. DATA ACQUISITION AND ANALYSIS

To acquire real traffic-induced vibration data, we deployed two BeanDevice AX-3D accelerometers in two different locations of Tamar Bridge (UK), as shown in Figure 1. We attached the nodes at the stiffening members under the bridge deck as they showed high amplitude vibrations. We collected data at different times of the day on two weekdays and correlate the datasets with vehicle traffic data at the bridge, provided by the Tamar Bridge and Torpoint Ferry Joint Committee (Figure 2).

We developed an LTspice model of the power supply system, including a power conditioning circuit (LTC3588-1), a six-stage voltage multiplier, and a 2 F storage supercapacitor, to determine the charge profile of the supercapacitor for each of the two locations. To this end, we conducted two sets of experiments in which we fed the power supply system model with the output voltage data obtained from a MATLAB model of an experimental prototype of the vibration energy harvester [1]. In each set of experiments, the harvester model was tuned to one of the resonant frequencies of the bridge, namely 9.1 Hz and 18.7 Hz, derived from power spectral density analysis of the collected acceleration data. Figure 3 shows the voltage curves across the supercapacitor obtained from these experiments.

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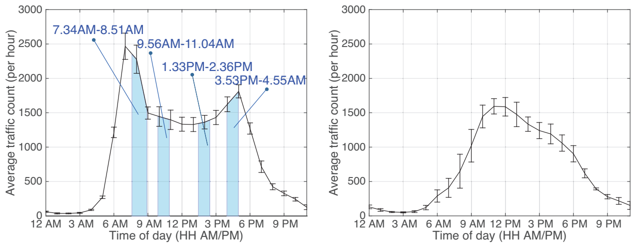


(a) Weekdays. (b) Weekends.

Figure 2: Average traffic at Tamar Bridge on weekdays (a) and weekends (b) in February 2016. Shaded areas indicate our data acquisition time intervals.

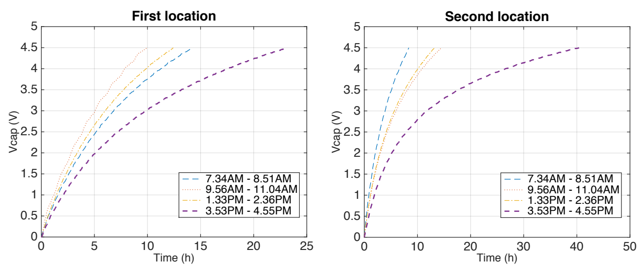


Figure 3: LTspice simulation results of the voltage across a 2 F supercapacitor using data collected from the two locations in Tamar Bridge.

3. SOFTWARE FRAMEWORK

We leverage the results of the power profiling in a comprehensive framework to conduct realistic simulated experiments in a multihop WSN before on-site deployment. The framework is shown in Figure 4, including the tools for power profiling and the WSN software, whose main components are detailed next.

The *application* is a simple program to get sensor readings at a given sampling rate. To simulate various charging patterns in several times of the day, we fit second-order polynomial models to the voltage curves obtained from the power profiling, and use a *script* to periodically compute V_{cap}, the voltage across the supercapacitor. The *energy monitor* updates the V_{cap} values by estimating the power consumption of each node, reusing the Energest component of the Contiki distribution. It also ensures that V_{cap} never falls below V_{cut}, the cut-off voltage of the power conditioning circuit, which would imply to wait a substantial amount of time for it to switch back on when V_{cap} reaches V_{on}, the startup voltage of the power conditioning circuit. A *multihop data forwarding* mechanism, based on a receiver-initiated MAC protocol with encounter optimization, allows for energy-aware multihop communication. A *queue management* module maintains a packet queue at each node and triggers packets transmission. All the software components are implemented for the Contiki OS.

4. PRELIMINARY EVALUATION

We resort to low traffic applications for bridge structural monitoring (e.g., corrosion assessment, measurement of concrete temperature or moisture content) to validate the frame-

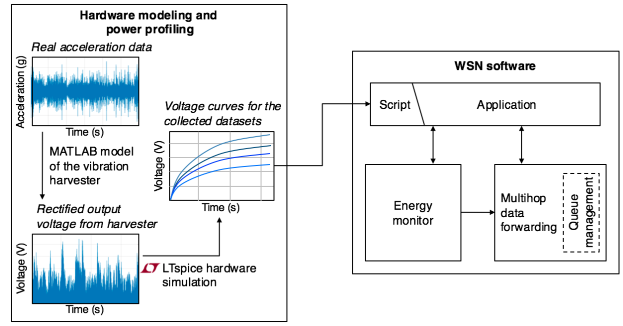
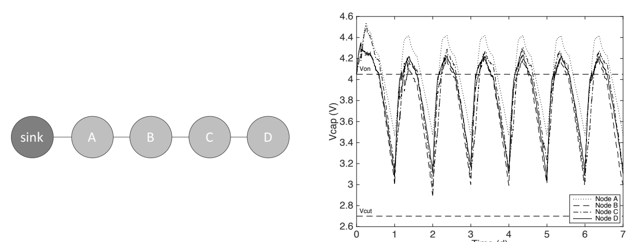


Figure 4: Framework for simulating vibration energy harvesting WSNs.

work within the COOJA/ MSPSim simulator. We consider a relatively small WSN, namely a chain of 5 nodes, including the *sink* (Figure 5a), which are based on the TI MSP430FR5969 FRAM MCU coupled with a TI CC2520 transceiver. We use the first set of models for nodes A and C, whereas the second set for nodes B and D. We use a 32-bit integer value to represent a single sensor reading. We also set: wake-up interval of the MAC protocol to 16 s, sampling period to 10 min, packet queue size = 16, V_{on} = 4.05 V, V_{cut} = 2.7 V. We run a one-week simulation and trace the values of V_{cap} at every node over time. Results are shown in Figure 5b and prove the effectiveness of the system as well as its ability to maintain *energy neutral operation*.

We believe this is the first attempt at building a real bridge monitoring framework based on vibration energy. We plan to test the system for different kinds of bridge structures and deploy it in a real-word scenario.



(a) Network topology. (b) V_{cap} traces over time.

Figure 5: Simulation experiments: (a) topology of the WSN; (b) V_{cap} traces over one week.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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