Bridge structural monitoring through a vibration energy harvesting wireless sensor network

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Background and motivation

Harvesting **traffic-induced vibrations** to operate wireless sensor networks (WSNs) for monitoring **bridge structures** is a valid alternative to energy generation when the use of other energy sources (e.g., sunlight, wind) is precluded by environmental conditions or deployment constraints.

Vibrations provide **lower performance** in terms of harvested power density than other energy sources.

Trade-offs arise from the interaction between energy source, energy storage device used, multihop communication protocol, and application requirements.

Solution

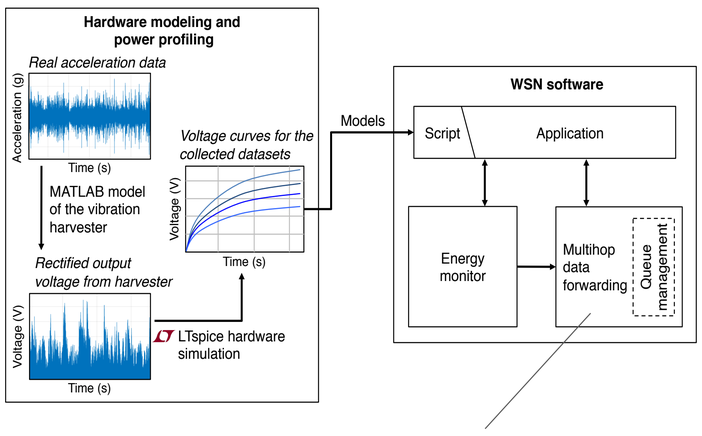
Comprehensive framework based on a vibration energy harvester, where:

- the sensor platform is based on **FRAM** technology and a **supercapacitor** is used as energy buffer
- **real acceleration data** are used to determine the charge profile of the supercapacitor and design a **receiver-initiated** protocol allowing for **multihop** communication

Software framework

Leverage the results of the power profiling in a comprehensive framework to conduct realistic experiments in a multihop WSN:

- **script** fed with the models periodically computes Vcap
- **energy monitor** estimates the power consumption
- **multihop data forwarding** mechanism allows for energy-aware multihop communication
- **queue management** triggers packet transmission

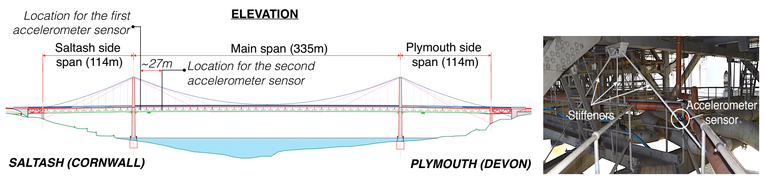


based on the RI-MAC protocol

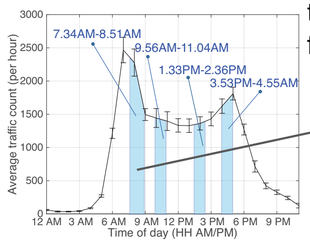
Data acquisition and analysis

Real-traffic vibration data collected from two accelerometers:

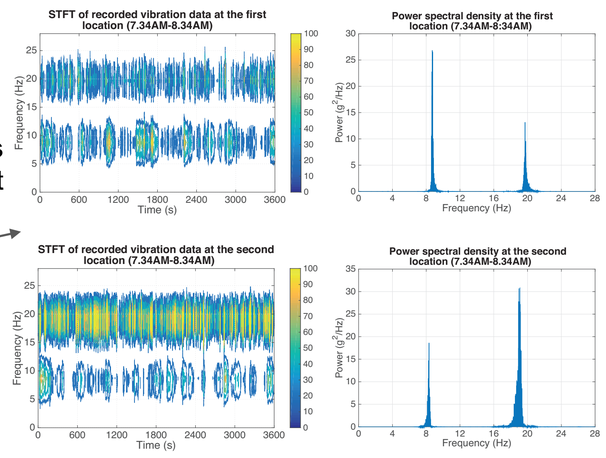
- deployed in two locations of **Tamar Bridge (UK)**



- at different times of the day to capture **different traffic volumes**

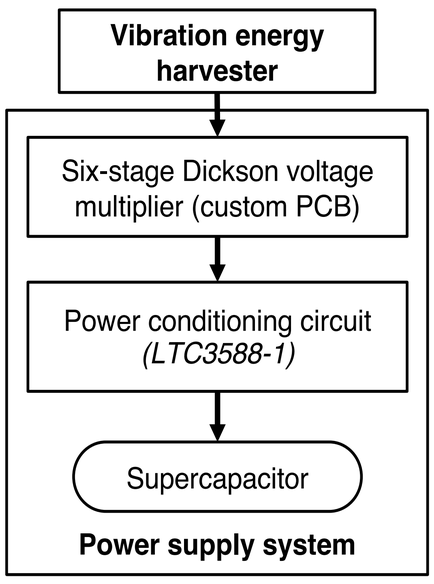


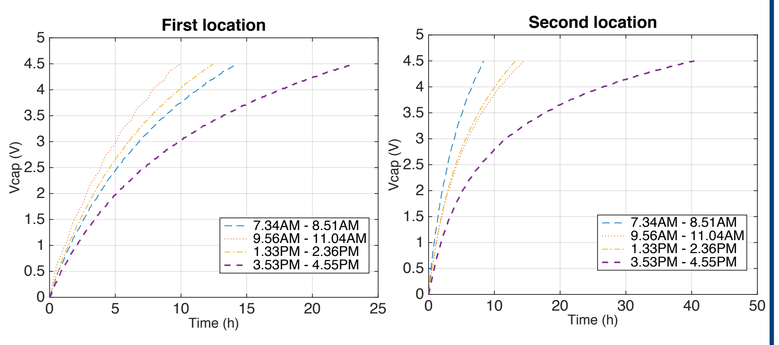
Power spectral analysis to find the resonant frequencies of the bridge



Two sets of experiments (one for each location) to determine the voltage charge profiles of a 2 F supercapacitor:

- **LTspice** model of the power supply system fed with the output voltage data obtained from a **MATLAB** model of a vibration energy harvester
- harvester model tuned to the resonant frequencies of the bridge (9.1 Hz and 18.7 Hz) derived from power spectral analysis





Fit **second-order polynomial models** to the voltage curves to enable network simulation experiments

Evaluation

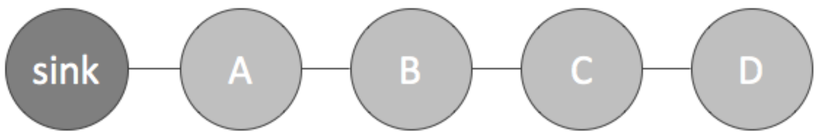
Low traffic applications for bridge structural monitoring (e.g., corrosion assessment, measurement of concrete temperature or moisture content).

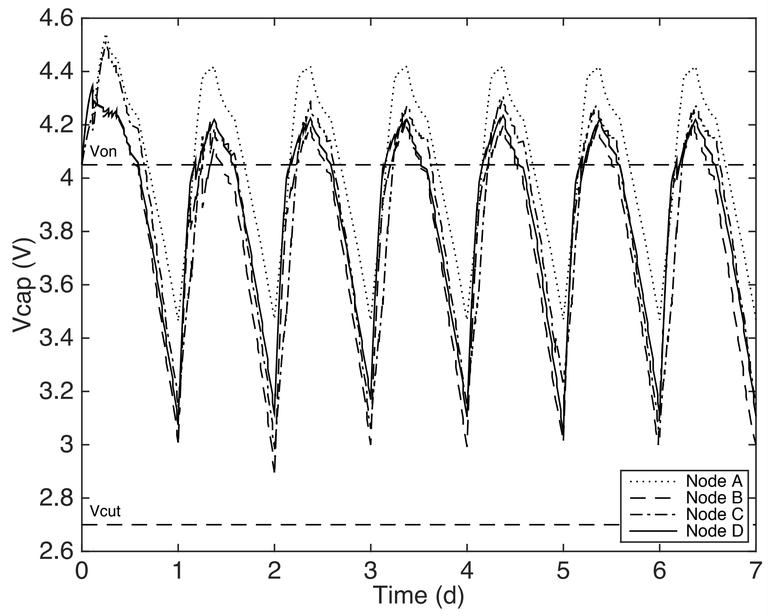
COOJA simulations:

- chain of 5 nodes based on the TI MSP430FR5969 FRAM MCU coupled with a TI CC2520 transceiver
- first set of models used for nodes A and C, second set used for nodes B and D

Setup:

- sampling period = 10 min
- wake-up interval = 16 s
- tx power = 0 dBm
- packet queue size = 16
- Von = 4.05 V, Vcut = 2.7 V





Energy neutral operation maintained over one-week simulation time

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