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

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

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

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