DEMO: Ultralow-power Collection Protocol for Wireless Sensor Networks in Structural Health Monitoring applications

Sapienza, University of Rome

Green sEnsor NEtworks for Structural monitoring

GENESI develops structural health monitoring systems for critical infrastructures such as tunnels, bridges, dams, private and public buildings, providing cutting edge green wireless sensor networks technology

KEYWORDS: structural health monitoring, energy harvesting, wireless sensor networks

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Introduction

Wireless Sensor Networks (WSNs) are made of battery-powered tiny devices with built-in memory, radio transceiver and central processing unit. Each of these devices, also known as sensor nodes, can hold one or more sensors able to retrieve some physical characteristic from the surrounding environment. The sensed data is collected through a dynamically built multi-hop wireless network toward one or more collection centres.

WSNs are easy to deploy and do not require any additional infrastructure to meet their clearly defined objectives thus they are well suited for Structural Health Monitoring. WSNs are expected to run unattended for several years since battery replacement, in such scenarios, is a difficult and cumbersome task. However, the limited energy of resources makes a sensor node, operating at full load (radio+cpu), to exhaust its power reserve in less than a week. A possible solution to address this issue consists in designing energy-aware protocols for WSNs. Since the radio transceiver is the most power hungry component (it consumes about 10 times the power required by the cpu), most of energy efficient solutions aim at reducing the energy consumption of the communication stack. In particular, solutions proposed in the literature increase network lifetime by turning the radio transceiver on and off. The duty cycle (i.e. the ratio between the on time and total time) is the most effective metric to measure the energy efficiency. Protocols which operate in Ultra-Low duty cycles (less than 1%) are the most energy efficient solutions currently available. They enable a WSN to exceed one year of network life time at the cost of a limited performance degradation in terms of latency and throughput (within what can be tolerated in GENESI application of interest). Further improvements able to make a WSN based system last decades or more require to be able to 1) reduce energy storage leakage (e.g., by means of fuel cells), 2) exploit energy harvesting and/or consume energy only when needed (radio triggering concept). On going activities address design of the protocol stack for the final GENESI system. This demo shows a first solution which has been fully designed and tested at this stage of the project activities. Such solution combines sensor nodes, interface with multiple structural health monitoring sensors and the DISSense MAC/Routing protocol stack which is part of the background of the University of Roma team.

In the following we first describe the sensor platform adopted for our demo, as well as the sensors and the interfaces which have been developed to integrate SHM sensors to the sensor node. We then briefly describe the communication protocol stack and the demo itself.

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II. Nodes and sensors

For sake of this demo we have used Telos (rev B) sensor nodes, developed by Crossbow Technology, Inc. Crossbow's TelosB mote is an open source platform designed to enable experimentation of cutting-edge protocols and solutions by the research community.

Figure 1: TelosB node

TelosB bundles all the essentials for lab studies into a single platform including: USB programming capability, an IEEE 802.15.4 radio with integrated antenna, a low-power MCU with extended memory, and some on board sensors.

The TelosB sensor node offers many features, including:

- IEEE 802.15.4/ZigBee compliant RF transceiver
- 250 kbps data rate
- Integrated onboard antenna
- 8MHz TI MSP430 microcontroller with 10kB RAM
- Low current consumption
- 1MB external flash for data logging
- Programming and data collection via USB
- Optional sensor suite including integrated light, temperature and humidity sensor

We have selected TelosB as it has similar performance and design than what is expected by GENESI platforms and supports TinyOS.

For the demo we interfaced TelosB with an heterogeneous suite of sensor devices, ranging from the canonical built-in sensors (specifically we used the light sensor) to different kind of strain gauge sensors. The light sensors mounted on board of the sensor nodes used for the demo are photodiodes from Hamamatsu Corporation. Default diodes are the S1087 for sensing photo synthetically active radiation and the S1087-01 for sensing the entire visible spectrum. We have also interfaced the node with commercial vibrating wire strain gauges and with resistive strain gauges. These devices are used to monitor strain in steel or in reinforce concrete and massive concrete structures. The strain gauge has been mounted on an external board in order to offer the demo attendees the possibility to see how stressing the strain guage results into different deformation values.

The resistive strain gauge is a KFG-3-120-C1-11L1M2R model of the Omega Strain gauges. It is composed of Constantan foil 6 μm thick with a nominal resistance of 120 ±0.4 ohms.

Figure 2: Resistive strain gauge

The small interface board connected to the strain gauge implements a Wheatstone bridge.

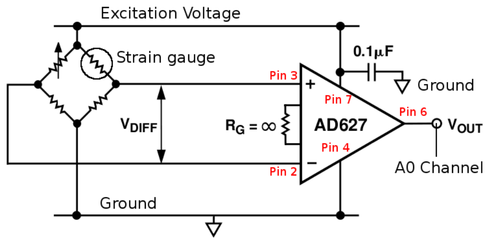

Figure 4: Interface to resistive strain gauge

Figure 5. displays a picture of the interface with commercial vibrating wire strain-gauge we have developed.

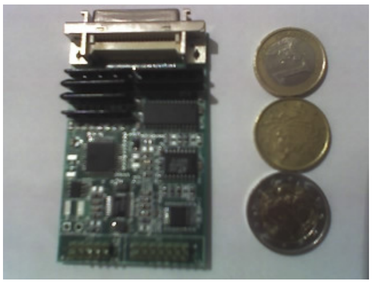

Figure 5: Interface with vibrating wire strain gauge

The developed interface supports 6 mechanical sensor input lines, is able to support a wide power supply voltage range, has been designed to reduce power consumption, supports sleep mode. In particular the off the shelf commercial vibrating wire strain gauge chosen for the demo, based on what has been selected by Treesse for SHM monitoring during the construction works of the Rome underground B1 line, is a OVK4200VC00 model provided by SISGEO with a typical frequency of 800Hz and a sensitivity of 1.0με

Figure 6: strain gauge

III DISSense description

DISSense provides both a data dissemination and collection service for WSNs. It targets structural health monitoring applications requiring periodic sampling of a given physical phenomenon. In particular, DISSense takes as input the desired sampling period and computes an adaptive time schedule for the nodes to coordinate in order to build a data collection tree. The schedule alternates short activity phases during which nodes deliver sensed data to the sink and long intervals during which nodes operate in an ultra low-power mode. Additionally, DISSense implements an efficient, one-to-many backward channel for disseminating the shared schedule to all nodes in the network.

Adaptation: DISSense achieves energy-efficient operation by adaptively shortening the length of the time interval during which nodes must activate their radio transceivers. Reducing the length of the active phase clearly enables DISSense to reduce the duty cycle of the network and, thus, to extend its lifetime. The main challenge arising in this context consists in making the protocol able to timely and reliably deliver data to the sink despite the shortening of the active phase. The diameter, density, and overall link quality of the network also affects protocol behavior. For example, reliable protocols such as DISSense may require several (re)transmission attempts over a bad link before at least one succeeds. Moreover, the denser the network the longer it takes to settle channel contention. And the higher the diameter of the network the higher the average number of hops packets must be relayed through before reaching the sink. By taking into account all these factors we make DISSense able to autonomously adapt its duty cycle to the actual dynamics of the network, and to ensure both high delivery ratios and energy efficiency.

Schedule: The sink is responsible for determining and disseminating the schedule according to which nodes send and receive their packets.

Figure 7 illustrates the different phases of the DISSense schedule: active phases are scheduled at each sampling period. Because of clock drifts and of the long inactivity period between active phases, a GuardTime Interval (GT) is foreseen at the beginning of each phase.

Moreover, a resynchronization procedure periodically takes place during the Resynchronization Interval (RI), so as to realign the schedule and compensate for clock drifts. Depending on the sampling period and intervals length, DISSense is able to skip the RI for one or more sampling periods, so as to optimize the overall protocol duty cycle. During the RI, nodes exchanges routing beacons and collect the information needed to build a collection tree having the sink as its root.

At the end of the RI, DISSense ensure that the nodes share a common wakeup time for the next active phase, and have a parent selected in the collection tree for data transmission.

After the RI, the Data Collection Interval (DCI) begins. During the DCI each node sends its data over the already built collection tree, and also act as forwarders for other nodes of the network. Between two active phases, DISSense turns into an Ultra-Low-Power State (ULPS) by switching the radio to LPL mode with a 0.1% duty cycle. In ULPS the radio is not turned fully off since some nodes may be added and other ones can go out of synchronization. Both these nodes need to retrieve the protocol schedule in order to participate to the network. The value of the duty cycle during ULPS is low so that it does not significantly affect the overall protocol duty cycle.

The active phase of DISSense runs on a CSMA/CA MAC with 100% duty cycled radio such as to accelerate the construction of the collection tree and the data collection process itself, thereby shortening the length of the active phase.

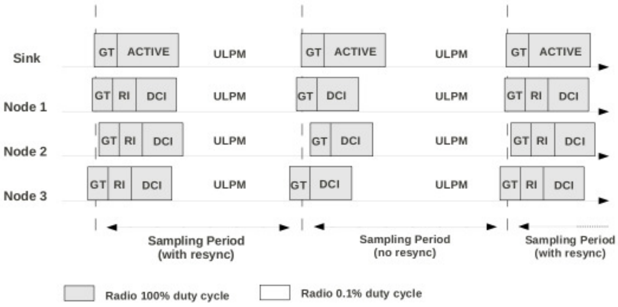

Figure 7 DISSense schedule

Collection and Backward Channel: Data collection in DISSense is achieved by leveraging and extending the CTP Collection protocol. CTP is a popular and highly reliable collection protocol. When running CTP each node computes a metric, called ETX, which represents the estimated number of transmissions a packet from this node will go through before reaching the sink.

CTP also supports loop detection, duplicate transmission and quick reaction to topology changes. However, CTP is not optimized for applications requiring short active phase sessions interleaved with inactivity periods, such as the scenario we are taking into account.

Instead, DISSense allows to stop, start, pause, and reset the construction and maintenance of the collection tree at any time. The backward channel in DISSense is used by the sink to resynchronize the network and to send schedule changes to nodes (e.g. intervals length and changes in sampling period). A node missing a schedule update is likely to loose synchronization with the other nodes. DISSense implements a backward channel, namely the Implicit Backward Channel (ICB), that guarantees that each node node having selected a parent in the collection tree, also shares the same values sent by the sink over the ICB during the active phase.

The ICB runs during the RI and uses the same beacons required for the collection tree construction.

The main advantage of this solution is that the RI interval can be tailored on the collection tree construction only since the ICB execution does not require any additional time.

IV. DEMO description

We present a Wireless Sensor Network, running the DISSense protocol, composed of 8 battery-powered sensor nodes. Each node is equipped with one sensor as follows:

- One node is interfaced with the resistive strain gauge.
- One node is connected to the sampling board that provides readings from the vibrating strain gauge
- The remaining 6 nodes provide environmental light measurements from the built-in sensors.

The sampling period chosen for this demo is set to 1 minute. At each sampling period the data collected by the network is displayed on the application's GUI. The GUI also displays, on the left side, the overall protocol performance (duty-cycle, delivery ratio of data packets, etc.) On the rest of the screen, the GUI shows the real-time network topology and useful readings.

During the demo we show how the sensor nodes detect changes in the environment and how the new data is forwarded to the base station. For what concerns the light sensor, we shows the different reading with and without a dark obstacle over it. The resistive strain gauge is manually bent in order to simulate a building façade deformation while on the vibrating strain-gauge we vary the pressure over the sensor trough a small vice devices.

V. RESULTS

This demo has the objective to reach an intuition on performance of current GENESI development. It shows in operation some of the sensors which have been interconnected to the sensor nodes. It also demonstrates that the DISsense protocol is able to extend a WSN lifespan some order of magnitude above other solutions. The ultra-low duty cycle, obtained by the protocol during previous experiments, allows the network to operate longer than the normal discharge period of the battery pack.

VI. AUTHORS & CONTACTS

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