**Abstract**

Object tracking applications are gaining popularity and will soon utilize Energy Harvesting (EH) low-power wireless nodes where power is mostly consumed for neighbor discovery (ND). Such applications require design with low-power neighbor discovery protocols. Although ND protocols were developed for sensor networks, the challenges posed by emerging EH low-power transceivers were not addressed. Therefore, we design an ND protocol tailored for the characteristics of a representative EH prototype: the TI ez430-RF2500-SEH. We demonstrate the Panda protocol [1, 2] implementation using commercial off-the-shelf energy harvesting devices, based on the TI ez430-RF2500-SEH prototype. The prototypes harvest indoor light energy to perform power-aware neighbor discovery, while maintaining a power budget. A custom-designed online monitoring system interactively demonstrates the wireless network dynamics, including the energy levels of the devices, the neighbor discovery events, and aggregate discovery statistics.

**Panda – Power-Aware Neighbor Discovery Asynchronously**

**Panda Protocol**
- Objective: Maximize the rate at which nodes discover their neighbors, subject to a power budget at each energy harvesting node
- Energy harvesting nodes transition between different radio states (sleep, listen, receive, and transmit) to maintain within a power budget. The node sleep duration is adjusted based on power harvesting feedback from the energy storage level (i.e., capacitor voltage)
- The average node sleep duration is set as function of it energy storage level
- Panda achieves energy neutrality by stabilizing the capacitor voltage at a target value

**Prototype based on the TI eZ430-RF2500-SEH**

**Energy Storage**
- An external 10 mF capacitor stores harvested energy to power up the prototype
- Prevented from reaching a low voltage level by imposing a software cutoff

**Energy Harvesting Prototype Testbed Network Demonstration**

Testbed includes:
- Small network of EH prototypes harvest energy from the light control system
- Programmable light control system for finely controlled dynamic light energy inputs
- An online monitoring system

**Demo showcases:**
- The energy harvesting rates at the nodes can be changed by increasing or reducing the amount of light incident on the solar cells
- Power-aware neighbor discovery: nodes with a higher energy harvesting rate are more active, and listen more frequently than nodes with a lower energy harvesting rate
- Network dynamics in real time

**References**

**Online Monitoring System**

A real time Graphical User Interface (GUI) based on Python and the Python Tkinter package

**Node States and Discovery Events:**
- The network dynamics are shown by a toposcape window
- A node ”blinks” when it transmits a message
- A directed edge occurs when a discovery event happens (e.g., node receives a discovery message from node 1)

**Energy Storage Level:**
- The capacitor voltage of each node represents its energy storage level
- Energy neutrality is demonstrated by the voltage oscillating within the limits of the capacitor voltage

**Neighbor Discovery Statistics:**
- The statistics includes the average neighbor discovery rate for both individual node and the network, as well as the discovery latency

**Recent and Future Work**

Distributed broadcast throughput maximization
- Explore the fundamental limits in the communication rate between a set of heterogeneous energy-constrained nodes. Consider two alternative definitions of throughput: Groupput and Anyput
- Design, analyze, and experiment with Energy-constrained Broadcast (EcoCast) protocol – a simple asynchronous in which nodes transition between sleep, listen, and transmit states in a distributed manner, and dynamically change the transition rates between different states

**Open Problems**
- Testbed evaluation of EcoCast with custom designed ultra-low-power nodes with improved energy awareness
- Consider unique application specifications (e.g., neighbor discovery and delay tolerant networks) and their relation to groupput and anyput

**Demo Abstract: Power-Aware Neighbor Discovery for Energy Harvesting Things**

Tingjun Chen¹, Greg Chen², Saahil Jain², Robert Margolies¹, Guy Grebla¹, Dan Rubenstein², and Gil Zussman¹
¹Electrical Engineering and ²Computer Science, Columbia University, New York, NY, USA

enhtans.ee.columbia.edu