Separating Synchronization and Communication to Build the Smart Building

Communications synchronization is the fundamental problem that limits node size and lifetime in low-power wireless sensor networks [3, 6]. Synchronization is necessary for efficient communication. When bootstrapping, prior work has fallen back on energy-expensive methods leveraging the communication channel *itself* and then must continously burn power with expensive real-time clocks to maintain synchronization. My **hypothesis** is that *decoupling synchronization from communication* will solve this problem, that such decoupling is possible using established RF (for bi-directional communications) and emerging visual light communications (for uni-directional synchronization), and that this decoupling enables smaller nodes *and* longer lifetimes. This will enable maintence-free lifetime monitoring and control of the energy-efficient Smart Building.

Intellectual Merit. The originality of this research is the observation that synchronization can be disentangled from the communications channel in wireless sensor networks (WSNs). The proposed research seeks to (i) decouple *synchronization* from *communication*, enabling entirely new classes of sensor nodes; (ii) develop an efficient building-scale sensor network backbone; (iii) develop a new information channel for medium access control (MAC) protocol design, enabling a new class of low-power MAC protocols; and (iv) explore a novel solution to room-level localization that drastically simplifies sensor network deployments.

Broader Impact. For buildings, this technology provides an unprecedented level of data. This data can be used to improve energy efficiency. For example, buildings no longer need to run wire to every window to disable HVACs when windows are open. Buildings can now control and adapt their energy consumption, deferring transient utilizations until the sun peeks out from behind the cloud again. The collected data can be used to improve Energy Star and LEED programs by better understanding where energy is needlessly lost. Solving the indoor localization problem, where GPS fails, opens a new class of technologies for general consumers, such as accurate indoor navigation or accurate room occupancy counting.

Background and Qualifications. I love the idea of the Internet of Things. I am impassioned by technology that automates and improves the world. During my final undergraduate years and my nascent graducate career, I have been working with Prabal Dutta, a preeminent researcher in sensor networks. Previous coursework and research experience extend from circuit theory and design through computer architecture to systems design, networking, security, and complex adaptive systems. As a computer engineer with greater than average breadth across the entire computing platform, my knowledge and experience positions me well for the challenges of low-power wireless sensor research.

Previous Work. The WSN community has developed many novel MAC protocols in recent years in effort to solve the energy-hungry communication challenge. All of these protocols share the common trait that they (1) require sychronization and (2) use the communication channel to bootstrap and preserve sychronization. In particular, recent efforts by Yerva et al. to develop a completely battery-less sensor node successfully solved the communication problem, but ultimately they were forced to resort to a battery and all of its negatives (size, cost, environmental impact, node lifetime) to provide the synchronization primative [6].

The key inspiration for this research came from my work with the Michigan Micro Mote initiative. The team developed FLOW, a 695 **pico**-Watt optical receiver [2]. Yerva et al.

found that in low amounts of indoor light they could still harvest 12.7 μW/cm^2, over four orders of magnitude greater. Even with only intermittent harvesting, an *always-on* visual light receiver with FLOW's power budget forms a viable system.

Research Plan. The first step in evaluating my hypothesis is to establish a visual light link. This will require development of both a transmitter and receiver circuit. For the first generation, more reliable high-power components will be used to establish the viability of the visual light channel without the complications of low-power hardware.

The next goal is to build a powerline communications (PLC) network. Previous research indicates that building-scale PLC networks loosely resemble disjoint wireless mesh networks and lessons and protocols from the field can be applied [5, 1]. I anticipate the construction of this network to be the most challenging aspect of this work, taking up to a year to solve the full-building connectivity problem. As an initial approach, I intend to build a hybrid light bulb, with both a PLC modem and 802.15.4 radio, relying on the physical proximity of electrically disjoint networks found in [5] to create a building-wide network.

Once a building-wide network of bulbs is in place, existing WSN protocols will need to be augmented to use the new visual light communications (VLC) channel. As a first pass, the VLC network can simply beacon a heartbeat or timestamp signal, requiring no modification of existing MACs for new sensors to take advantage of the new channel. One insight towards integration, however, is that existing WSNs require a gateway node to bridge their low-power wireless protocols with the Internet proper. These gateways are generally always-on devices that are plugged into the wall and thus the newly extant PLC network. By selectively triggering bulbs, the gateway is able to control individual sesnsor nodes and establish which room the sensors are located in.

By this point in time, the expectation is that the FLOW hardware will have matured to a point that integration with commerical products is feasible. By integrating the evolved FLOW hardware into Yerva et al.'s Gecko nodes, the newly developed VLC network will enable truly battery-less, multi-hop WSN nodes.

Limitations. The localization problem was only deferred to localizing the bulbs. One solution to explore is the addition of a VLC receiver circuit to each bulb, generating steady-state and transient connectivity graphs to feed into Lu et al.'s Smart Blueprints system [4].

Keywords: embedded, wireless sensor networks, communication, visual light, powerline

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