Self-Powered Wireless Sensor Network with Energy Conscious Opportunistic Routing

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***Abstract*—With energy being the most valuable resource in self-powered Wireless Sensor Networks (WSNs), the ability to monitor individual node power levels and route accordingly becomes crucial to ensure longevity of a network's lifetime. In this paper, an Energy Conscious Opportunistic Routing Protocol (ECORP) is demonstrated, which allows energy conservation measures to be implemented without hindering the latency of important packets. In the experimental testbed, all relay nodes harvest energy via solar panels, with a shared relay node forcing inconsistently dispersed network traffic. By implementing ECORP, gross network power reserves are minimized upon network failure, extending the network's lifetime.**

I. Introduction

Wireless Sensor Networks (WSNs) develop at a rapid pace due to the wide range of applications made available by this flexible technology. One prominent issue with WSNs are power limitations which can severely constrict network lifetime. To combat WSN power limitations, self-powered networks with rechargeable batteries are often implemented. Even with advances in energy harvesting capabilities, energy efficient sensors, and energy conserving routing protocols, inconsistencies within networks such as imbalanced loads and non-ideal energy harvesting environments can be crippling. There are however alternative solutions available to accommodate these network inconsistencies and help ensure longevity of a network's lifetime.

Opportunistic routing protocols are one solution to promote network lifetime through the use of dynamic routing decisions. Opportunistic routing takes advantage of the physical communication layer, dynamically selecting the next node based on availability and other instantaneous network conditions [1]. Therefore, the success of an opportunistic routing protocol is determined by the selection metrics for the next node [2]. This paper extends the idea of Energy Conserving Opportunistic Routing introduced in [3], proposing an alternative *Energy Conscious Opportunistic Routing Protocol* (ECORP). The previous energy conserving protocol ensures that self-powered nodes with less energy available have time to recharge, which is accomplished by the introduction of a delay into the network's throughput. An alternative protocol is proposed which still ensures that self-powered nodes with less energy have time to recharge, without the introduction of a network delay.

II. System Architecture

The system architecture for the self-powered WSN consist of a multitude of hardware components that create the hardware infrastructure. This hardware infrastructure is then utilized in varying combinations to create the system framework.

A. Hardware Infrastructure

The four components that make up the hardware infrastructure are the sensor units, the OPM15 development board, the prototype power converter, and the energy harvesting solar panel. Each component provides different functionality to the system, and their combinations allow for the development of the system framework.

1) Sensor Units: Two different sensors are utilized in order to collect environmental data. The iAQ-2000 carbon dioxide (CO_2) sensor is a cost effective solution to accurately monitor the air quality of an indoor environment [4]. This sensor communicates using the RS-232 communication protocol and consumes only $46mW$ of power while active, making it ideal for long term monitoring applications. The monitored CO_2 levels are translated into a parts-per-million value, which can be correlated to the air quality of an indoor environment.

The second sensor is the AD22100 monolithic analog temperature sensor, with an accurate monitoring range of -50°to +150°and on-chip signal conditioning [5]. This device requires a fixed $5V$ supply and consumes only $2.5mW$ of power while running. By monitoring the ambient temperature of a room, the air quality of an indoor environment can be correlated.

2) OPM15 Development Board: The OPM15 development board by RapidMesh provides wireless capabilities for a network through its opportunistic wireless mesh radio [6]. This low-power device ($41\ mW$ during active cycle) is designed for low bandwidth applications. The microchip PIC18F26K22 programmable microcontroller enables networks to be quickly developed through open-source C based applications. As well, the OPM15 is easily interfaced to additional components through SPI, I^{2}C, or RS-232, and has multiple free analog and digital ports available.

3) Prototype Power Converter: A prototype multi-functional power converter has been provided for experimental use [7]. The prototype provides an all-in-one solution to power management and interfacing requirements between common hardware components. The prototype is capable of boosting and regulating an input voltage to a fixed $5V$s, has a built in shutoff to protect the battery source from over-draining, is capable of recharging a lithium polymer (LiPo) battery with the aid of an energy harvesting device, and provides terminals to access the input power source's voltage. A toggle switch also enables the power to be solely drawn from an energy harvesting device instead of a LiPo battery.

4) Energy Harvesting Solar Panel: The Star Solar D165X165 monocrystalline solar cell provides energy harvesting functionality to the system. This solar cell produces a $6V$ potential with an optimal power production of $4.5\ W$ in laboratory conditions, making it a cost effective solution when designing a self-powered network. It is small in size $(165\ \times 165\ \times 2.5\ mm)$ and comes ready to be interfaced to other components through a barrel connector.

B. System Framework

The system framework is comprised of three separate modules. The wireless monitoring modules, the relay modules, and the base-station module all utilize the previously described hardware infrastructure.

1) Wireless Monitoring Modules: The wireless monitoring modules serve to collect environmental data and forward this information in the direction of the destination node. Two prototypes have been developed which are capable of collecting either CO_2 or temperature measurements from the surrounding environment. These prototypes consist of a sensor unit and an OPM15.

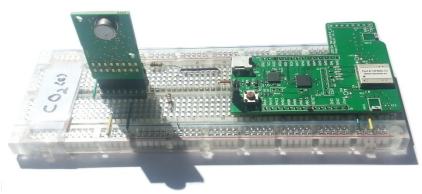

Fig. 1: Carbon Dioxide Monitoring Module.

The first prototype is capable of detecting the indoor air quality of a room by utilizing the iAQ-2000 CO_2 sensor. This sensor is interfaced with an OPM15 development board by using the RS-232 communication protocol, which also provides wireless capabilities for the module. The prototype is powered through the mini-USB port on the OMP15, which requires a fixed $5V$ power supply. The wireless CO_2 monitoring module can be seen in Fig. 1.

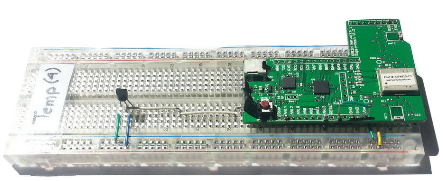

Fig. 2: Temperature Monitoring Module.

The second prototype is the wireless temperature monitoring module that uses the AD22100 temperature sensor to collect environmental data. This sensor is interfaced through an analog port on the OPM15, allowing for this prototype to also have wireless capabilities. Similar to the previous prototype, it is powered through the mini-USB port and can be seen in Fig. 2.

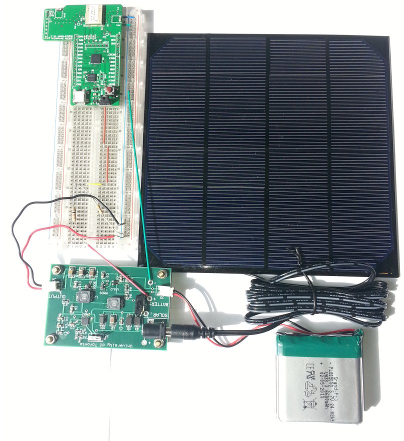

Fig. 3: Relay Module With Energy Harvesting Capabilities.

2) Relay Modules: Several prototype relay modules have been developed to enable communication within the network between the wireless monitoring modules and the base-station module. One of the prototypes can be seen in Fig. 3. These prototypes are built from several hardware components, those being an OPM15, a prototype power converter, and an energy harvesting solar panel. In addition to these components, a Lithium Polymer (LiPo) battery provides external power. The OPM15 holds dual functions within the relay module, providing wireless capabilities for the node while also monitoring the LiPo battery's remaining power. By taking advantage of the high resolution Analog to Digital Converter (ADC) within the OPM15, the battery's voltage can be translated into a battery level percentage. This translation allows for the remaining power of each node to be monitored quickly and accurately without the requirement for additional hardware components.

The relay module's remaining hardware components give the node self-powered capabilities. The prototype power adapter has been interfaced with the solar panel, the LiPo battery, and the OPM15, regulating power for the OPM15 while also converting energy from the solar panel into a stored electric potential within the battery.

3) Base-Station Module: The base-station module acts as the final destination for the information forwarded by the relay nodes. It consists of only an OPM15 and a portable computer. The portable computer is connected to the OPM15 through a mini-USB cable, providing a fixed $5V$ power supply to the module while also enabling RS-232 communication. Every packet received by the base station module is displayed through a simple User Interface (UI), which contains information regarding the environmental data collected, the path that the packet traveled, and the battery level of the visited relay node. This information is then stored by the UI for offline analysis.

III. Energy Conscious Opportunistic Routing

The proposed ECORP is dynamic in nature, using opportunistic routing as the foundation. A specific selection criteria has been developed to help minimize the gross network power upon network failure. This in turn helps to maximize network lifetime by attempting to drain the power of each available node equally. Nodes with less power are given time to recharge through their energy harvesting capabilities, reducing the chance of an isolated network failure.

The selection criteria for the next node is based upon the nodes that are currently available, as well as various network conditions. Before a node sends a packet of information in the direction of the destination node, a two-way Request to Send/ Clear to Send (RTS/CTS) handshake occurs with neighbor nodes. Embedded within this handshake is information regarding the neighbor nodes' current battery level. Once all available neighbor nodes have responded, the selection of the most appropriate node for transmission can occur.

A simple selection process determines which node will be the receiver of a unicast transmission. Currently the only metric in the next node selection process is remaining power, which results in the node with the highest amount of remaining power to be selected. By choosing to transmit data through nodes with more available power, nodes with dwindling power supplies have the opportunity to harvest energy and avoid network failure due to overuse.

The proposed opportunistic routing protocol avoids the introduction of a delay into the network during the next node selection process, by instead introducing an overhead of 4 bytes into the RTS/ CTS handshake. By choosing this location for embedding information, the network maintains the dynamic capabilities of opportunistic routing. Something worth noting is that this protocols strength is also its weakness. By avoiding nodes with less energy, the chances for an isolated network failure to occur is reduced significantly. However this intrinsically means that as all nodes are drained in a somewhat equal manner, which increases the risk of nodal failure in rapid succession. Therefore the application is highly important in selecting an appropriate opportunistic routing protocol, as well as a clearly defined description of network failure for that application.

IV. Experimental Setup

A scalable scenario has been developed with a total of 6 nodes distributed in three columns, following a $2-3-1$ fashion. The network setup has been depicted in Fig. 4. The first column consists of two monitoring modules which are directly powered through a USB cable, with one module collecting temperature data and the other collecting CO_2 data. These two nodes then generate packets periodically and send the data in the direction of the destination node. The second column consists of 3 equally spaced, self-powered relay modules. This distribution results in each monitoring node sharing a common relay node, creating the potential for an imbalanced network load. The third column consists of only the base-station module that is connected directly to a computer, displaying the information regarding the sensor readings as well as the path traveled by each packet through the UI.

Two different protocols will be tested on the described scenario to showcase the strength of the ECORP. The first routing protocol randomly selects the relay node for transmission each time a packet is generated at the monitoring modules. This protocol will run until network failure, providing a baseline for the network lifetime. The second protocol will implement the proposed ECORP, with identical packet generation cycles within the monitoring modules. Again, this protocol will run until network failure occurs. In these tests, network failure is defined as when the first node within the network fails.

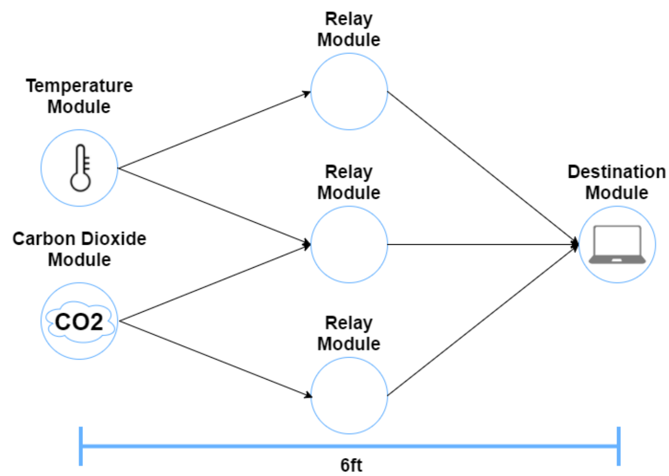

Fig. 4: Demonstration Layout Following a $2-3-1$ Distribution.

V. Conclusion

This paper presents an energy conscious opportunistic routing protocol for an energy harvesting WSN. When network traffic remains inconsistence across all nodes, network failure will occur quicker than that with an appropriately dispersed routing protocol. With the presented ECORP, gross network power reserves can be minimized upon network failure, thus increasing the longevity of network lifetime in the process.

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