A Solar-Powered Wireless Data Acquisition Network

E90: Senior Design Project Proposal

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Abstract

We are proposing to design and implement a solar-powered wireless network for remote sensory data acquisition. With data being transmitted wirelessly over distances of up to 1.6 km and power harvested from solar energy, such a network would be ideally suited for situations in which sensory data needs to be gathered from remote open locations with no access to ground power. In order to ensure minimum power consumption, all of the digital circuitry is going to be powered by 3.3V and the wireless transceivers used are going to conform to the low-power ZigBee standard (IEEE 802.15.4). Constant power input will be maintained using a simple trickle charger connected to a rechargeable battery. The cost of one network node, which will include a wireless transceiver and a PIC microcontroller for data acquisition and network support, will be approximately $100.

Introduction

The goal of this project is to build an autonomous wireless data acquisition system that will offer a seamless and cost-effective solution to the problem of gathering remote sensory data. A good example of where such a system would be particularly useful is environmental monitoring. Since all of the data is transferred wirelessly and the power is harvested from the sun, all one needs to do in order to install our remote sensory system is ensure access to solar energy and conform to our specification for maximum distance between the different nodes. Beyond that, installation would consist merely of attaching the analog sensor inputs to the module and collecting the data on the other end. As a result, engineers using our system would require virtually no knowledge of how the system operates in order to install it, since the network topology and data acquisition algorithms will be pre-programmed on the PIC microcontroller at each node. Of course, we will still allow the user to modify the system parameters to better suit his or her specific needs by using Flash-based PICs in our design and providing a serial jack that would enable reprogramming. In the end, we hope for a product that comes at a reasonable price and is both versatile and easy to use.

Technical Discussion

The wireless transceivers that we chose for our design are the Xbee and XbeePRO, which conform to the IEEE 802.15.4 standard and are offered by MaxStream, Inc. The IEEE 802.15.4 wireless standard, more commonly known as ZigBee is ideally suited for our project. Similarly to the more popular and established IEEE 802.11b and Bluetooth standards, it operates in the commercial 2.4 GHz (ISM) radio band. The specification allows for up to 255 network nodes and maximum transfer rates of 250 Kbps at a range of 30 meters. The ZigBee technology is slower than 802.11b (11 Mbps) and Bluetooth (1 Mbps) but consumes significantly less power. This makes the IEEE 802.15.4 standard particularly suitable for our project, since it was specifically designed for data gathering applications with relatively low transfer rates and limited power resources.

The Xbee, which is going to be used for short-range communication, transmits data over a distance of up to 100 m in line of sight, drawing a current of only 45 mA at 3.3 V power supply voltage. Its receive current is 50 mA. The XbeePro can transfer data over a distance of up to 1.6 km in line of sight, drawing 270 mA of current at 3.3 V, while using only 55 mA when in receiver mode. Both modules allow for an ultra-low power sleep mode, in which they draw less than 10 μA. Therefore, with careful scheduling of the periods of time, during which the modules are transmitting and receiving data, one could achieve a level of power consumption that would be sufficiently low for the modules to be powered solely by solar energy. For more detailed information on the specifications of the two wireless modems, please refer to Appendix I.

In order to ensure the efficient and accurate operation of our sensory network, we can use a PIC F16LH737 microcontroller to gather the data from the analog sensors and store it in external memory, as well as send commands to the Xbee wireless modems. This microcontroller is based on Microchip's nanoWatt technology and runs on supply voltages as low as 2.0 V at a frequency of 4 MHz (refer to datasheet in Appendix II).

Using the PIC in combination with a 16K EEPROM chip, we would be able to minimize the time during which the Xbee and XbeePRO wireless modems are in transmission mode, since we would only go into this mode when a sufficiently large amount of data to be transferred has accumulated. In order to conserve power, the PIC will also operate mostly in an ultra-low power sleep mode, waking up periodically to collect data and write it to memory or communicate with the wireless serial modem. Finally, since each node is going to have its own PIC and the PICs are going to be able to communicate with each other, we should be able to alter the topology of our network in real time and implement simple routing algorithms that would allow the system to continue functioning even in the case when some nodes are down.

We plan to use a 16K SPI Bus Serial EEPROM chip from Microchip to temporarily store data between transmission cycles. There are a number of benefits to using EEPROM memory for our project. First of all, it consumes very little power. In particular, the read current is 2.5 mA at a supply voltage of 2.5 V and a clock frequency of 5 MHz, and the wire current is 3 mA (refer to data sheet in Appendix III). The current drawn while in the standby mode is as low as 1 μA at 2.5 V. Therefore, this EEPROM chip will be able to operate at sufficiently low power, while at the same time it can be clocked at the frequency of the PIC, which will be 4 MHz. Also, in the case where the module loses power due to persistent lack of sunlight, the data that has already been written to memory but has not yet been transmitted would remain intact since EEPROM is non-volatile.

For the power supply portion of our project, we will use a relatively simple solar trickle charger. The energy from the solar panels is going to get stored in a rechargeable battery that will power the entire module. The battery is going to provide a steady power supply, which is crucial for the correct operation of the Xbee modules. Currently, we are considering purchasing a SoLite Flexible Solar Battery Charger, which would charge either 2 or 4 AA NiMH batteries in 5-8 hours of sunshine. The SoLite charger is particularly suited for our project needs since its simple design allows us to make easy modifications in case we decide to add additional functionality to the charger beyond the diode it currently has protecting the batteries from discharging. In addition to this, the solar panels of the charger are weather-proof, which is also crucial to our design.

Our rough preliminary power calculation indicates that if 1) the PIC is in a low-power standby mode 50% of the time, 2) the EEPROM is in R/W mode 50% the time, 3) we transmit 10% of the time and we receive 10% of the time, and 4) the efficiency of the DC-DC converter is 90%, we would require less than 50 mA of current per hour. The power rating on a NiMH battery is about 2300 mAh. Therefore, our circuit would be able to operate for about 46 hours off 2 AA NiMH batteries, and 92 hours off 4 AA NiMH batteries. All of these calculations were made for the nodes containing the XbeePRO transceiver module, which requires considerably more transmission current than the Xbee module.

We are going to use a DC-DC converter to scale the battery voltage down to an operating voltage of 3.3 V in case we choose to use 4 AA batteries in series to power our circuit. We chose to use a DC-DC converter instead of the much simpler voltage regulator, since DC-DC converters have a much higher energy efficiency ratings. The DC-DC converter we chose for our project is the V7AH-03H3300 which has an input voltage range of 4.5 – 32 V, an output voltage of 3.3 V, and an efficiency rating of 90%.

We should be able to power our entire circuit using a 3.3 V power supply, since all of the analog and digital circuitry we will use can operate at this voltage. For more information on the DC-DC converter, please refer to the data sheet in Appendix IV.

Finally, in terms of software development, we plan to write a program in C that would gather the data from each network node and store it on a web server. This program would acquire all of the data that reaches the final node of our network through the PC serial port, and then simply send it to a server on the local campus network. The program would be designed so that it can run reliably in the background without taking up too much of the host PC's resources, and it would be included in the list of programs that run on startup. Thus, the data collected by the analog sensors would be readily available at all times and easily accessible through the World Wide Web.

Figure 1 below presents a block diagram for a single node, including all signal and power connections.

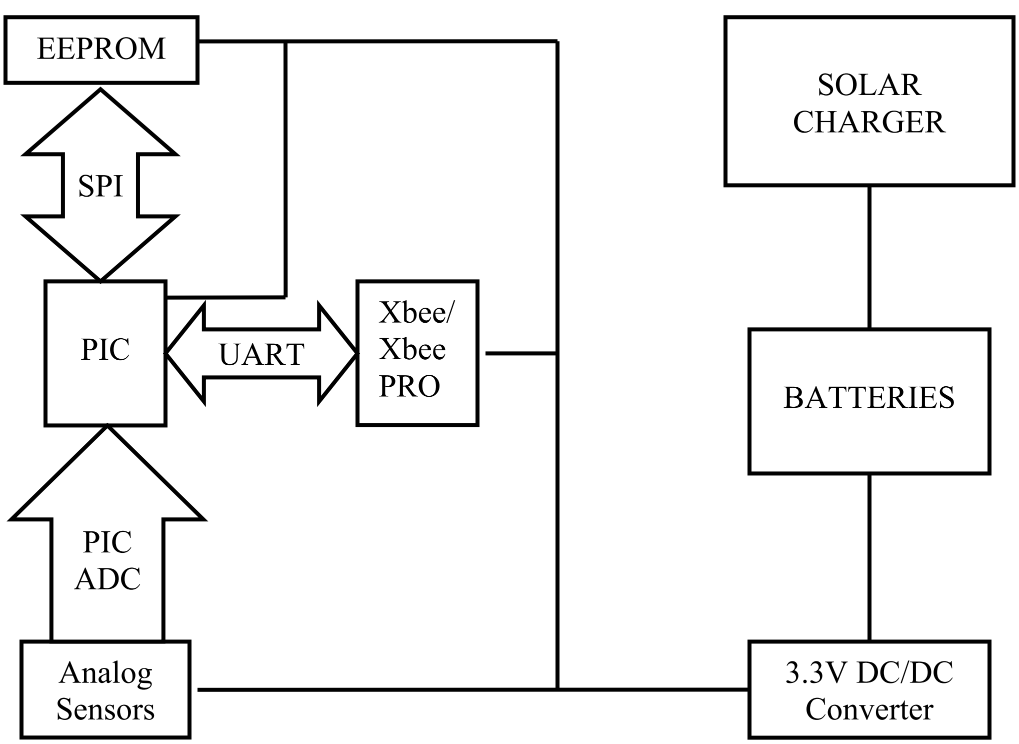

Figure 1. Single Network Node Block Diagram

Figure 2 below presents an example network topology, including maximum distances for master-to-master and master-to-slave wireless communication.

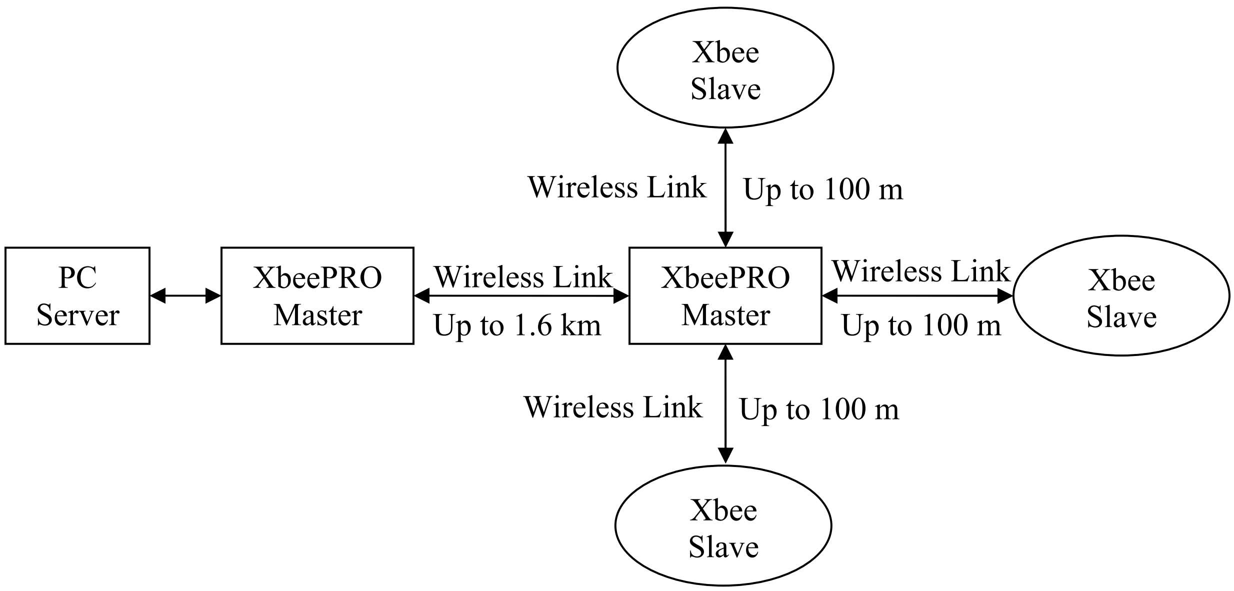

Figure 2. Example Network Topology

Project Plan

Activity	Duration	Effort	Needs	Feeds	Action
					Determine power requirements.
					Order wireless transceiver chips.
					Order PICs.
					Order memory chips.
A	2d	4h		B	Order batteries and solar panels.
B	1d	2h	B	I	Order DC to DC converters for digital circuitry.
C	2d	3h		I,K	Order analog sensors (temperature, pressure, etc.) and DC to DC converters for analog circuitry.
D	5d	5h		F	Establish communication between transceiver modules.
E	3d	7h		F	Establish connection between PIC and memory.
F	5d	12h	D,E	G	Setup up serial communications between PIC microcontroller and transceiver module. Provide software and schematic documentation.
G	5d	10h	F	H	Choose and develop networking protocol.
H	7d	17h	G	L	Establish wireless communication between PIC microcontrollers. Provide software documentation.
I	10d	18h	B,C	J	Design battery charging circuit. Provide schematic documentation.
J	7d	10h	I	L	Test battery charging circuit.
K	2d	4h	C	L	Test analog sensors.
L	10d	15h	H,J,K	M	Design a PCB to incorporate all hardware: PIC, memory, sensors, transceivers, battery, solar panel, DC to DC converters.
M	5d	1h	L	O	Manufacture board. Provide schematic documentation.
N	10d	20h		P	Develop web interface. Provide software documentation.
O	3-10d	10-25h	M	R	Test and debug PCB.
P	3d	5h	P	R	Setup web server for data acquisition.
Q	4d	8h		R	Build a case to protect the hardware.
R	7-10d	10-20h	O,P,Q	S	Test entire system in realistic conditions.
S	5d	25h	R		Write report.

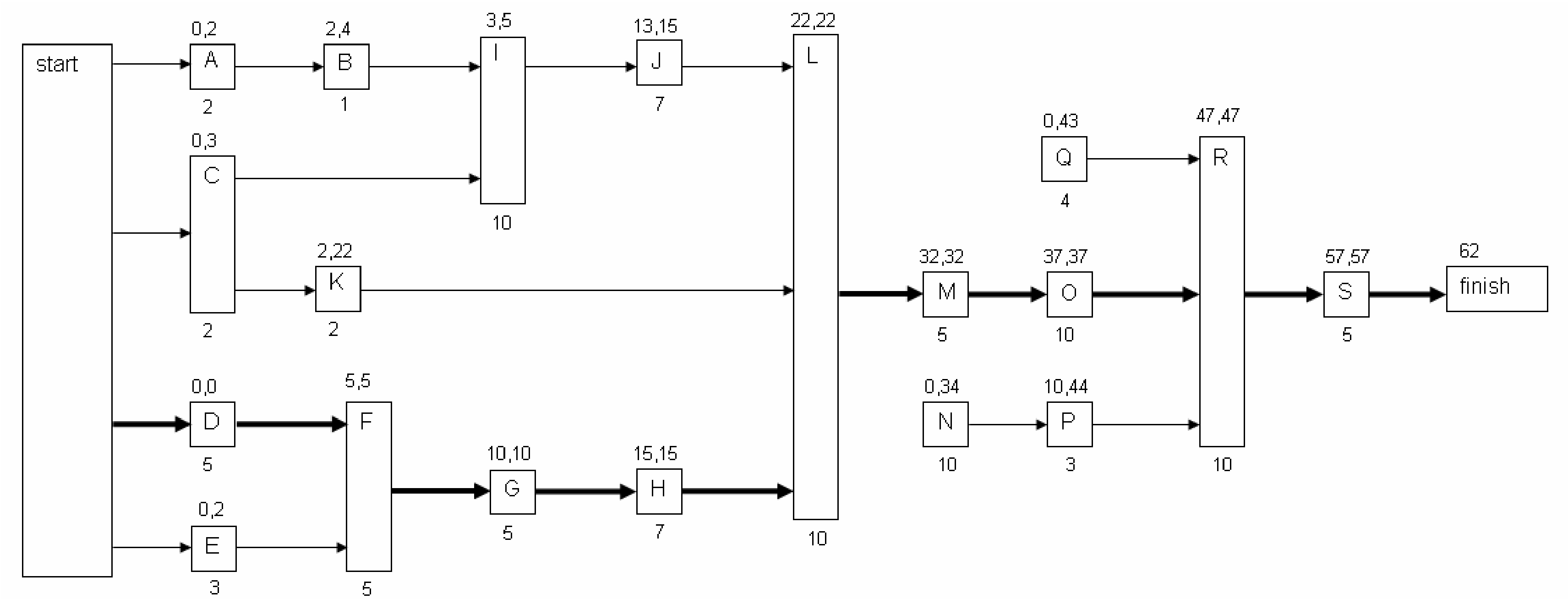

Figure 3. CPM Network Diagram

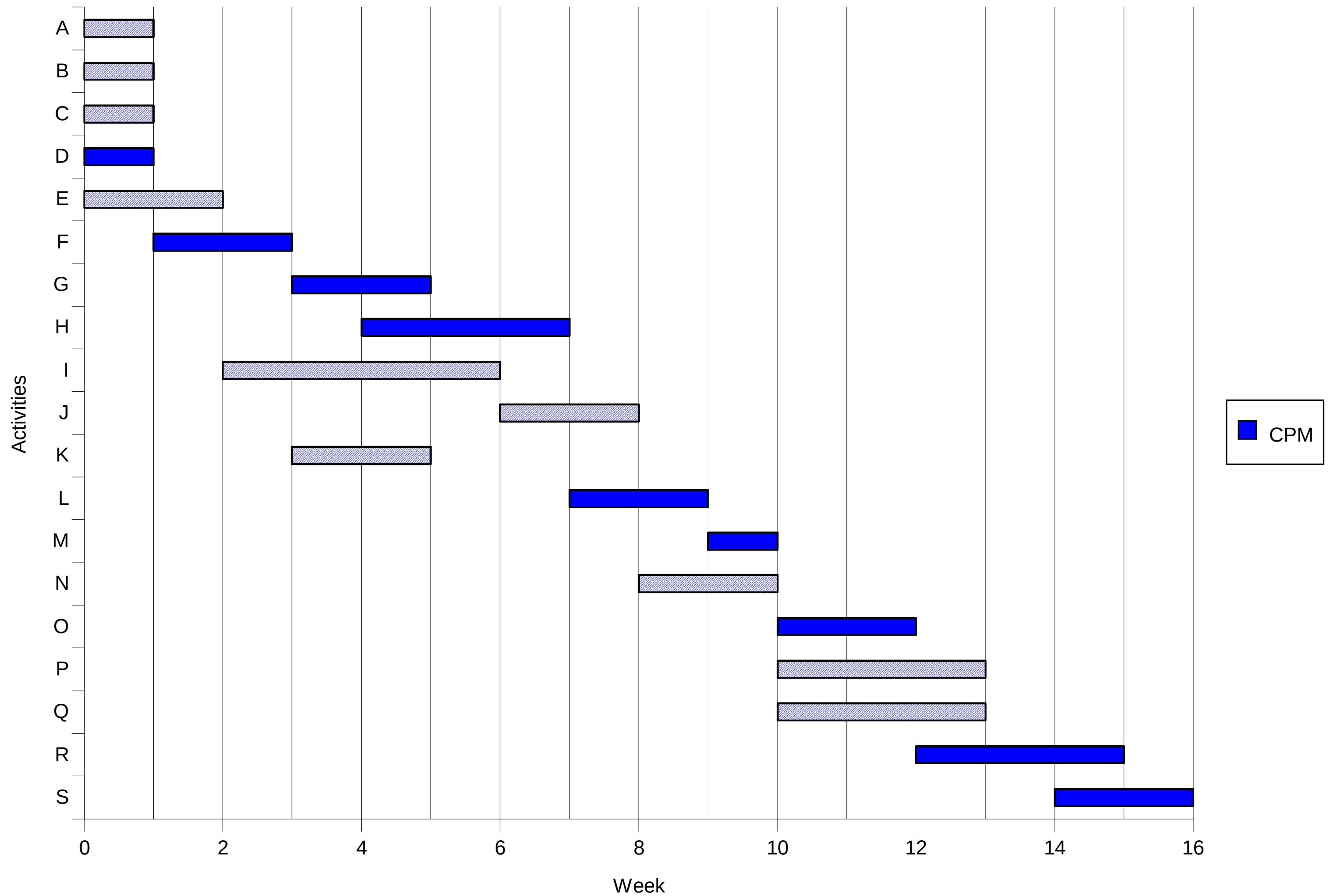

Figure 4. GANTT Chart

Project Qualifications

We feel that we have the necessary background and experience that will allow us to complete the proposed project on time. Either through taking classes such as *E14: Experimentation for Engineering Design, E72: Electronic Circuit Applications*, and *E78: Communication Systems*, or through relevant research experience, we have developed the technical skills necessary to undertake a project such as the one being proposed. In particular, our class work has provided us with the necessary theoretical background to ascertain the feasibility of our project goals, as well as make the necessary preliminary design calculations. Our experience with embedded system design and serial wireless communication also provides us with the essential practical knowledge a project of this scale requires.

Project Costs

Part Name	Part Description	Unit Price	Number of Units	Price
Xbee	Wireless Modem (100 m)	$19.00	3	$57.00
XbeePRO	Wireless Modem (1.6 km)	$32.00	2	$64.00
25AA160A	16K SPI EEPROM	$0.99	4	$3.96
PIC16LF737	PIC microcontroller	$6.80	4	$27.20
LM19	Temperature Sensor	$0.77	4	$3.08
SolLite Flexible Solar Battery Charger	Solar Charger – 4 AA batteries	$29.95	4	$119.8
POWEREX 2300 mAh AA NiMH	Rechargeable Battery (4 batteries per pack)	$8.57	4	$34.28
V7AH-03H3300	DC-DC converter	$13.90	4	$55.60
			Additional Costs (PCB manufacturing, product shipping, etc.)	$100.00
			Total Cost	**$464.92**

NOTES:

1. In addition to the components listed above, our project is going to require a number of generic circuit components such as transistors, resistors, capacitors, etc. that the Department already has available, so we have not included them in our project costs.

2. We are going to require weekly meetings of 1-2 hours with our advisor, Prof. Cheever.
3. All labor on the project is going to be performed by Brian Park and Simeon Realov, and it is going to be free.

Appendices

Appendix I
http://www.maxstream.net/products/ xbee/datasheet_XBee_OEM-RF-Module.pdf

Appendix II
http://ww1.microchip.com/downloads/en/DeviceDoc/30498c.pdf

Appendix III
http://ww1.microchip.com/downloads/en/DeviceDoc/21807b.pdf

Appendix IV
http://www.belfuse.com/Data/DBObject/x7AH-03H_DS_121704.pdf