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DESIGN OF POWER OPTIMIZATION MODULE IN A NETWORK OF ARDUINO-BASED WIRELESS SENSOR NODES

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ABSTRACT

Energy constraint is a major challenge in the deployment and applications of wireless sensor networks. The lifetime of the network depends solely on the node life of the composite units. To efficiently maximise the lifetime of the component nodes within the network, optimization of the available power is very crucial for consideration. This paper presents the design of a module to teach undergraduate students the step-by-step approach to optimizing the limited power available to specially designed wireless sensor network. Three different measures were introduced to guarantee the reduction in the power consumption within the network. There was 10% reduction in the power consumption and there was extension of the node lifetime from 26 hrs to 132 days. There was a feedback on the level of understanding of the 20 students taken at random. The results are then presented graphically.

Keywords: power optimization, wireless, sensor network, nodes, teach.

1. INTRODUCTION

Wireless sensor nodes in various network applications are often deployed with constrained energy sources. Roundy *et al.* [14] explained the results of a broad survey of possible potential energy sources for wireless sensor nodes to include both fixed energy sources such as batteries and power scavenging sources. As wireless sensor nodes are typically very small electronic devices, they could only be equipped with a limited power source of less than 0.5 - 2 ampere-hour and 1.2 - 3.7 volts. Scavenging energy from the environment and using this energy to power the sensor network device would greatly increase the effective lifetime of a wireless sensor node. As [16] has documented, there is ample power to scavenge from the human body. Fuel cells represent a potentially large improvement over batteries as an energy reservoir. Miniaturized fuel cells could extend the lifetime of a node up to several times that of a battery powered node. However, this is still a fixed energy source, and so would either require re-fuelling, or would have a limited lifetime [8, 13].

Sohraby [17] reported that the sensor node lifetime typically exhibits a strong dependency on battery life. In many cases, the wireless sensor node has a limited power source (<500 mAh, 1.2 V), and replenishment of power may be limited or impossible altogether. Battery operation for sensors used in commercial applications is typically based on two AA alkaline cells or one Li-AA cell. Meanwhile, power management and power conservation are critical functions for sensor networks, and one needs to design power-aware protocols and algorithms. Power consumption can therefore be allocated to three functional domains: sensing, communication, and data processing, each of which requires optimization [1].

To efficiently maximise the lifetime of the sensor nodes, optimization of the available power is a vital consideration. When the nodes are deployed; other aspects of the network which include circuits, architecture, algorithms and protocols are ensured to be energy efficient. A distributed, self-configuring network of adaptive sensors has significant power benefits. Among the previously developed algorithms for power optimization in wireless sensor networks is the Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm. Based on the report of [22], software power management techniques can greatly decrease the power consumed by RF sensor nodes. TDMA is especially useful for power conservation, since a node can power down or ‘sleep’ between its assigned time slots, waking up in time to receive and transmit messages. The required transmission power increases as the square of the distance between source and destination. Therefore, multiple short message transmission hops require less power than one long hop. In fact, if the distance between source and destination is R, the power required for single-hop transmission is proportional to R^2. If nodes between source and destination are taken advantage of to transmit n short hops instead, the power required by each node is proportional to R^2/n^2. This is a strong argument in favour of distributed networks with multiple nodes that is nets of the mesh variety. For n nodes randomly distributed in a disk, the network is asymptotically connected with probability one if the transmission range r of all nodes is selected using equation (1), where $\gamma(n)$ is a function that goes to infinity as n becomes large.

$$r \geq \sqrt{\log n + \gamma(n) \big/ \pi n} \tag{1}$$

Onibonoje [12] explained that effective learning and teaching of wireless sensor network (WSN) however, requires the students to gain hands-on experience in developing WSN projects, which help the students to understand the strength and limitations of WSN. This paper focuses on the design of a module to teach students on the use of controller power mode configuration and transceiver protocol modification to achieve power optimization in WSN.

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2. METHODOLOGY

The module is designed to show students a step-by-step approach to building the power optimization scheme into a developed Arduino-based wireless sensor nodes within a network.The basic composite unit blocks of the wireless sensor node is as shown in Figure-1. Each of the units within the sensor node depends on the constrained power source, mostly batteries for its operation. In other to optimising the consumption of power in the node, the various other hardware and software units would be modified for reduced energy sapping.

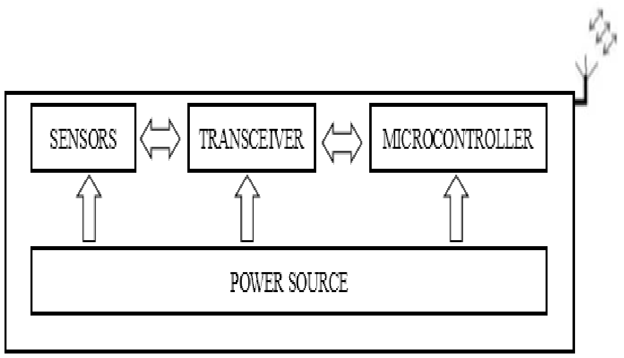

Figure-1. Composite units of a wireless sensor node.

2.1 Selection of composite units for optimization

The two crucial units for modification in the optimization process are the microcontroller and the radio module. Arduino board is a very good choice for the microcontroller, while XBee radio module performs a good function as a transceiver. Arduino board has a robust ecosystem for teaching students or beginners the concept of sensor integration. The XBee module consists of the radio transceiver, microprocessor, memory, and antenna [10, 11, 12]. The selected Arduino Pro mini board and XBee (S1) radio module are as shown in Figure-2.

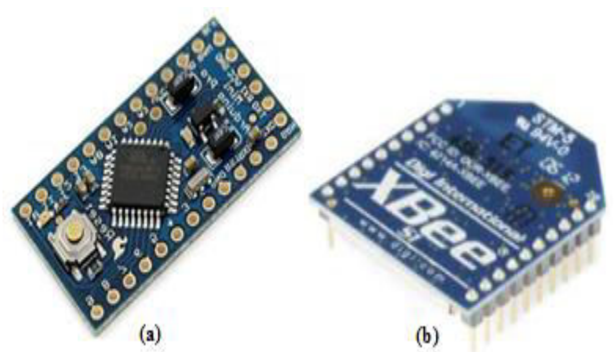

Figure-2. The selected component units of sensor node for modification, (a) Arduino Pro mini board, (b) XBee module.

2.2 Power consumption optimization

There are three different measures adopted in the power optimization approach: the reconfiguration of the radio module for cyclic sleeping mode, the modification of the Arduino board for a power-down mode, and the disability of the power indicators on the microcontroller board.

2.2.1 Configuration of radio module for sleep

The configuration of the module in sleep modes allows the radio frequency (RF) module to enter states of low power consumption when not in use. XBee RF modules support both pin sleep (sleep mode entered on pin transition) and cyclic sleep (module sleeps for a fixed time).A number of low-power modes exist to enable modules to operate for extended periods of time onbattery power.

Asynchronous sleep modes are used to control the sleep state on a module by module basis. Modules operating in asynchronous mode should never be used to route data. It is strongly encouraged that users set asynchronous sleeping modules as end-devices. This prevents the node from attempting to route data. The synchronous sleep modes makes it possible for all nodes in the network to synchronize their sleep and wake times. All synchronized cyclic sleep nodes enter and exit a low power state at the same time. This forms a cyclic sleeping network. Nodes synchronize by receiving a special RF packet called a sync message which is sent by a node acting as a sleep coordinator. A nodein the network can become a coordinator through a process called nomination. The sleep coordinator will send one sync message at the beginning of each wake period. The sync message is sent as a broadcast and repeated by every node in the network. Each node sent its sensed data during wake period and reverted to sleep. The power consumption during sleep mode was negligible, thereby saving energy. The sleep and wake times for the entire network can be changed by locally changing the settings on an individual node. The network will use the most recently set sleep settings.

These sleep modes are enabled with the SM command. The sleep modes are characterized as either asynchronous (SM = 1, 4, 5) or synchronous (SM = 7, 8). Do not use asynchronous sleeping modes in a synchronous sleeping network, and vice versa. The synchronization behaviour of the sleep compatible modules is as shown in Figure-3.

Synchronous sleep support mode (SM=7)

A node in synchronous sleep support mode will synchronize itself with a sleeping network, but willnot sleep itself. At any time, the node will respond to new nodes which are attempting to join the sleeping network with a sync message. A sleep support node only transmits normal data when the other nodes in the sleeping network are awake. Sleep support nodes are especially useful when used as preferred sleep coordinator nodes and as aids in adding new nodes to a sleeping network.

Synchronous cyclic sleep mode (SM=8)

A node in synchronous cyclic sleep mode sleeps for a programmed time, wakes in unison with other nodes, exchanges data and sync messages, and then returns to

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sleep. While asleep, it cannot receive RF messages or read commands from the UART port. Generally, sleep and wake times are specified by the SP and ST respectively of the network's sleep coordinator. These parameters are only used at start up until the node is synchronized with the network. When a module has synchronized with the network, its sleep and wake times can be queried with the OS and OW commands respectively.

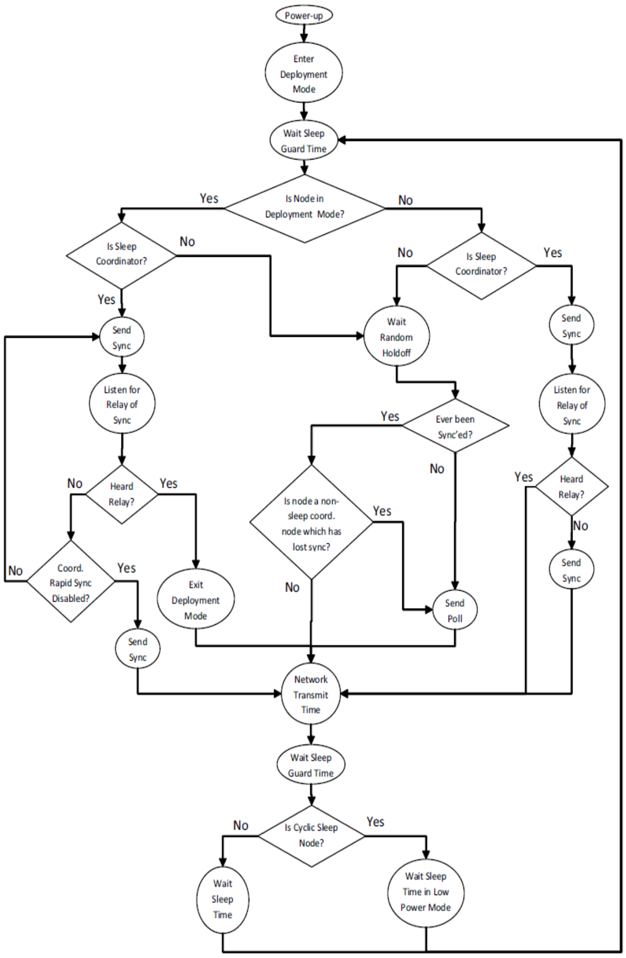

Figure-3. The synchronization behavior of sleep compatible RF modules.

If D9= 1 (On_SLEEPenabled) on a cyclic sleep node, the On_SLEEPline asserts when the module is awake and de-assert when the module is asleep. CTS is also de-asserted while asleep (D7 = 1). A newly-powered unsynchronized sleeping node will poll for a synchronized message and then sleep for theperiod specified by SP, repeating this cycle until it becomes synchronized by receiving a syncmessage. Once a sync message is received, the node synchronizes itself with the network.

The configuration of XBee & network was implemented using the serial terminal software XCTU (Configuration and Test Utility Software by Digi International) with AT commands. The configuration parameters are as shown in Tables (1) - (3).

Table-1. Configuration parameters for all nodes.

Parameters	Value
Port setting parameters	
Baud	9600
Data	8 bit
Parity	None
Stop bits	1
Flow control	None
MAC/PHY Setting	
Network ID	2345
Operating channel	C
Destination address	
High	0
Low	FFFF
I/O Setting	
Pull-up resistor	Enable (3FFF)
IR sampling rate	1388 (5s)

Table-2. Configuration parameters for sensor nodes (only).

Parameters	Value
Node identifier	Router
Serial interfacing	Transparent (0)
Sleep commands	
Sleep mode	Synchronous cyclic sleep (8)
Sleep time	14395s
Wake time	5s

Table-3. Configuration parameters for sink node (only).

Parameters	Value
Node identifier	Coordinator
Serial interfacing	API (Enable)
Sleep commands	
Sleep mode	Normal (0)

2.2.2 Modification of the Arduino board for a power-down

Powering down the Arduino Pro mini in each sensor node is another measure in optimizing the power consumption in the node. This step is achieved by installing a low-power library into the main library of the Arduino, and then the argument 'Low Power. power Down (SLEEP_14395s, ADC_OFF, BOD_OFF)' is included. The argument disables all unused peripheral on the board, thereby reducing the power consumption. Also, all chip functions were disabled till the next interrupt.

Only level interrupts on INT1 and INT2 pin changed interrupts, and WDT enabled did wake the MCU up.

2.2.3 Disability of the power LEDs on the Arduino boards

The third measure in the power optimization process is the disability of the indicator LEDs on the Arduino board. Considerable power is consumed by the two power LEDs on the Arduino boards. This measure is achieved by gently using a sharp-tipped metal to break the connections of the LEDs to the main board.

3. RESULTS AND DISCUSSIONS

3.1 Node life evaluation

The power consumption was reduced by 10% as shown in Table-4.

Table-4. Result of the power optimization due to board modification.

Element of power consumption	Value
Current drawn by unmodified board	4.74mA
Total current drawn by unmodified board and other peripherals	50.29mA
Current drawn by modified and power down board	0.0045mA
Total current drawn after modification	45.6mA
Power reduction and optimization	10%

Table-5. Result of the power optimization due to module sleep configuration.

Element of power consumption	Period
Data transmitted per second in fully awake radio module	26 hrs
Data transmitted 5 times per four hours in sleeping radio module	132 days

The node lifetime was extended from 26 hrs to 132 days approximately as shown in Table-5. One sensor node was powered with 9V alkaline battery with capacity 1200mAh. With the already modified microcontroller board, the total runs needed for the sensor node sending data were at least:

$$= \frac{1200\text{mAh}}{45.6\text{mAs}}$$

$$= \frac{1200 \times 3600}{45.6}$$

= 94737 times (with data transmitted every second)

= 26 hrs

In this research work, the result of the node lifetime estimation showed:

= 94737 ÷ (5 × 6 × 24) (data transmitted 5 times/ four hours)

= 132 days

3.2 Evaluation of the Module Impact

To determine the level of understanding of 20 randomly selected students, each of the student was allowed to independently implement the approach in the module. A feedback form was issued to the students to assess their level of understanding. The feedback result is as presented in Figure-4.

Figure-4. The feedback result of the students.

5. CONCLUSIONS

The paper concludes that the step-by-step power optimization scheme for wireless sensor network as highlighted in the module are instructive and presents a trainer platform for students interested in WSN projects. The result of the power optimization shows a reliable scheme with 10% reduction in power consumption and extension of node life from 26 hrs to 132 days. The feedback from the 20 randomly selected students also shows a very good impact factor on the users for future implementation.

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