International Journal of Recent Trends in Engineering, Vol 1, No. 4, May 2009

PICSENSE – A Wireless Sensor Network Testbed

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***Abstract*— This paper deals with the design of PICSENSE, a wireless sensor network testbed. Both hardware and software aspects of the design and the integration of the sensor networks with the TCP/IP network is also discussed. In this paper the firmware design for the PICSENSE is discussed elaborately. And to demonstrate the capabilities of the sensor network testbed, development of a power control application is also reported as a case study.**

***Index Terms*— Wireless Sensor Networks Testbed, Transmission Power control MAC, Embedded Web server**

I. Introduction

Wireless sensor network is the network of tiny sensor nodes, which will sense the physical parameters like temperature, humidity and sends it wirelessly to the base station or to the neighbouring node. A typical sensor node has a sensor, a microcontroller and a RF transceiver. The size of the sensor nodes are shrinking because of the rapid growth in the Integrated Circuit Technology, which leads to an IC having processor and RF transceiver in it. Wireless sensor networks are used in environment monitoring, habitat monitoring [1], smart agriculture and in many fields.

Wireless sensor networks is a interdisciplinary subject, which requires the knowledge of sensors, microprocessor based electronic hardware design, and Embedded communication software design. Much of the research in sensor networks is done on the embedded communication software design, which involves designing the protocol software in the tiny 8 bit processor. Many sensor nodes are battery powered. Larger proportion of battery power is spent on the radio communication as the transmission and reception of packets consumes more energy than the processor and the sensor. In many applications constant recharging or replacement of the battery for the sensor node makes wireless sensor network, not a viable solution. So research in wireless sensor networks focuses on the energy efficient communication software design. Though the researchers are using the simulations to verify their protocols, still in the simulation there are many approximations which make sometimes the results deviates much from the actual results. And moreover the same protocol implementation in different simulators gives the results which differ from one other not only quantitatively but also qualitatively [9]. These simulation results vary much widely because of the different radio model used in different simulators. While in the ad hoc networks, sensor network offers high ease of doing the implementation. So for the researchers, to test their protocols in actual sensor networks, it is required to have a standard wireless sensor network test bed. It is also required to have the software routines which will do the primitive operations like sending and receiving data through RF transceiver. This makes the life of researcher easy as the researcher can concentrate on the higher level protocol layer design. In this work we have described the design of PICSENSE, wireless sensor network test bed

The paper is organized as follows Section II discusses about the existing wireless sensor network testbed elaborately and the Section III describes the PICSENSE architecture. Section IV discusses about the design of gateway node. And Section V describes the application to demonstrate the power control algorithm implementation in PICSENSE test bed.

II. RELATED WORK

There are lots of wireless sensor network testbeds, proposed in the literature. Geoffrey Werner-Allen et al [2] has reported the design of MoteLab; a web based wireless sensor network testbed. MoteLab consists of set of nodes connected to central server which can be used for reprogramming, and data logging. As it provides web interface, remote users can access the testbed. A fair scheduling policy for the usage of the testbed via web is also designed. Energy measurement also can be done remotely via off the shelf instrument. It uses the MICA2 motes with Ethernet interface boards which facilitate the data logging and remote reprogramming.

Vlado Handziski et al [3] have reported the design of TWIST, a scalable and reconfigurable sensor network testbed. It has sensor nodes in the first tier which is connected via USB to the super node in the second tier which again is connected to the backbone Ethernet network. Telos mote is used as sensor node and tinyOS is used as operating system for the sensor nodes. It deals with the hardware design aspects of TWIST.

Wisebed [4] is an effort to integrate different sensor networks by connecting it to internet.

III. PICSENSE ARCHITECTURE

The PICSENSE is a single hop wireless sensor network testbed which will send the sensor information to the gateway node. The gateway node will act as an embedded web server which serves the web pages with the dynamic data.

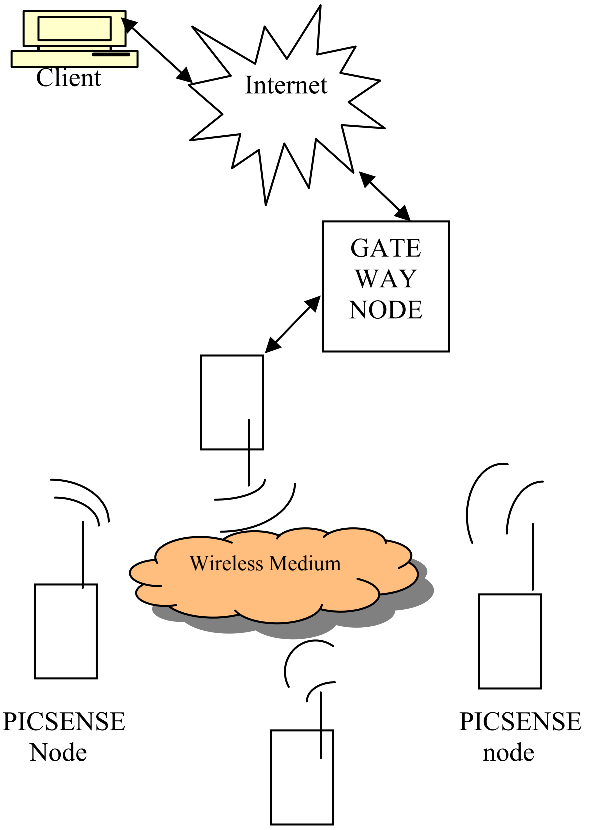

Figure 1: PICSENSE – A wireless sensor network Architecture

The client can give the query / command which will be disseminated among the wireless sensor nodes. The nodes respond to the query/command which will be collected by rabbit processor based gateway node. The updates will be served to client as http response.

A. Hardware Description

The core of the PICSENSE node is its microcontroller PIC18F4620. It has 64K flash, 4K RAM, 13 channel 10 bit Analog to Digital Converter to which the sensor output is connected. It has 1K EEPROM and Capture/Compare/PWM modules. PIC18F4620 works in three modes.

TABLE I. PIC18F4620 OPERATION MODES

	CPU	Peripherals
Normal	ON	ON
Idle	OFF	ON
Sleep	OFF	OFF

B. RF Transceiver

ADF7020-1 is a low power highly integrated FSK/GFSK/ASK/OOK/GOOK transceiver designed for operating in the low UHF and VHF band. The operating frequency for this transceiver can be set anywhere between 135MHz to 650MHz. By using the divide by two the operating frequency can be reduced to 80MHz

The transmitter output power is programmable in 63 steps from -20dBm to +13dBm. This is the feature which can be used by the researcher for implementing his/her power control algorithm. In this paper implementation of a power control algorithm by using this PICSENSE nodes are detailed as the demonstration of power control using PICSENSE testbed.

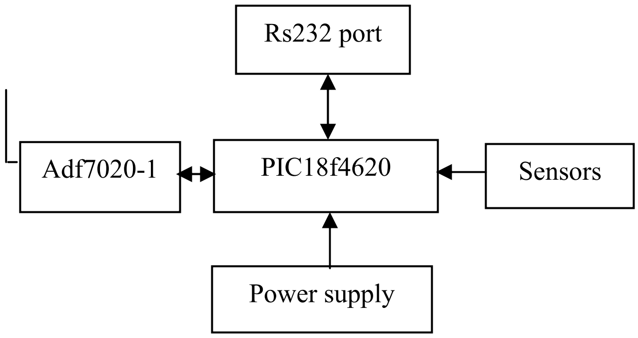

Figure 2. PICSENSE – Node Block Diagram

Figure 3. PICSENSE –Sensor node with Battery

The transmit section of ADF7020-1 contain a VCO and low noise fractional N-PLL with output resolution of <1ppm. This makes ADF7020-1 an ideal candidate for Frequency Hopping Spread Spectrum (FHSS). So the PICSENSE testbed can also be used to implement the multi channel algorithm. Here transceiver's RF output frequency is set to 433.92MHz and the RF baud rate is 9600.

The on chip ADC of ADF7020-1 provides read back of an integrated temperature sensor, an external analog input, a battery voltage or the RSSI signal which provides savings on the ADC in some applications. The transceiver module is interfaced with the processor through the SPI Interface.

C. Sensors

Apart from the internal temperature sensor of

ADF7020-1, there is a externally connected, LM35, an IC temperature sensor whose output voltage is linearly proposional to the centigrade temperature. It outputs 10mv for each 1˙ C temperature increment. The output of LM35 is connected to one of the ADC channels of PIC18f4620. As there are 13 analog channels, any sensor can be interfaced with the PICSENSE node easily.

To demonstrate the PWM based speed control, a speed measurement arrangement is done with MOC7811. The arrangement is shown in figure 4.

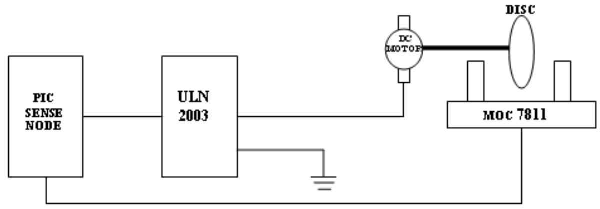

Figure 4. Speed sensing and control arrangement –Block diagram

D. Firmware Development

The software for the PIC18F4620 is developed by using CCS cross compiler. No middleware is used. Routines for the primitive operations like initializing the transceiver, sending and receiving a byte through RF transceiver has been developed. The communication software has been developed with the following packet structure

CRC0	CRC1	PL	DATA

Figure 5. Packet structure

First two bytes are for cyclic redundancy check (CRC). This is to ensure the packet integrity as the wireless channel is not reliable. The third byte holds the packet length (PL) which is the length of the data bytes followed. Here the Manchester encoding is done for the proper reception of data though the reception of continuous 1's or 0's occurred.

IV. RABBIT GATEWAY NODE

A. Hardware Description

The Rabbit Semiconductor's RCM4000 module development board is used as the gateway node. This module has rabbit 4000, a 16 bit processor which operates at the clock speed up to 60MHz. The processor also features I/O lines shared with five serial ports and four levels of alternate pin function that include variable phase PWM, auxiliary I/O, quadrature decoder and input capture. This module has an integrated 10 base T Ethernet port which allows the node to be connected to the IP networks. This microprocessor has 512K Flash and 512K SRAM. The wireless node is connected to the gateway node through the serial Interface and the gateway node is connected to the IP network through the switch.

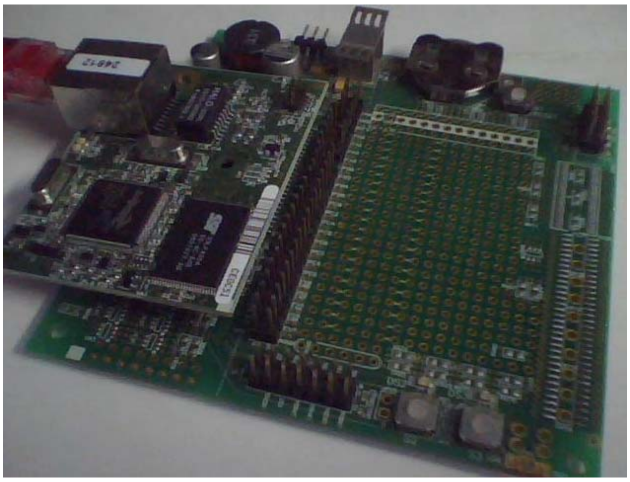

Figure 6. Rabbit RCM4000 Gateway Node

B. Firmware Development

In this PICSENSE testbed, the firmware is written in the gateway node such that it will act as a HTTP server so that there is no need for the specialized software in the client machine other than a simple browser.

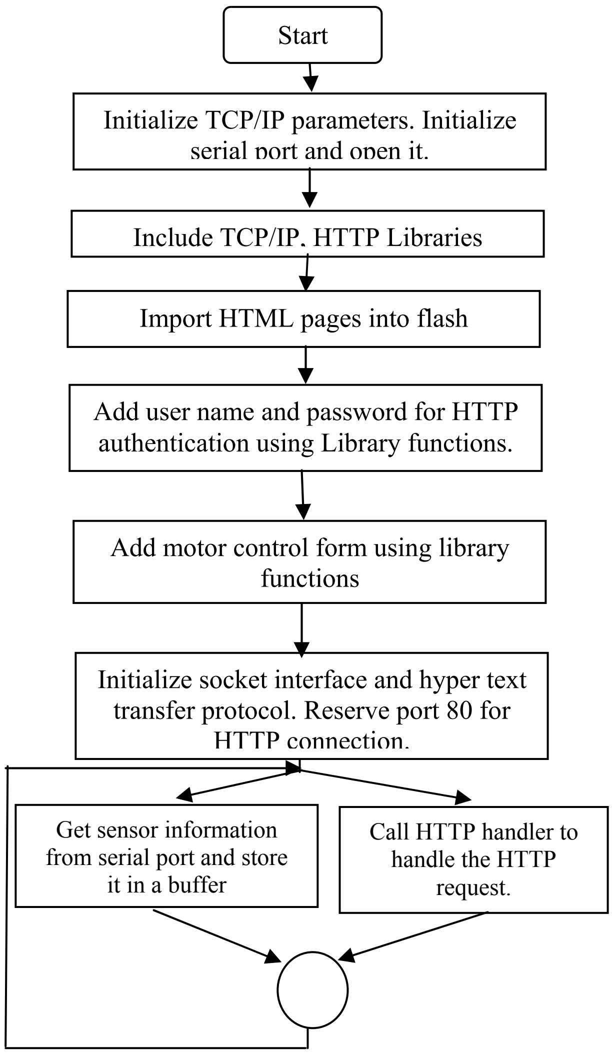

Figure 7. Algorithm for the Gateway Node

The firmware in the gateway is developed using Dynamic C IDE. This IDE has TCP/IP and HTTP libraries to support the development of embedded Ethernet application. The application along with the web pages is embedded into the processor memory. The web pages are developed with Server Side Include (SSI) directives to serve the dynamic sensor data to the client machine.

For the speed measurement and control, a HTTP form interface is used to monitor speed and to give the PWM duty cycle value to the server which in turn determines the speed of the motor. By this application, the usage of PICSENSE platform for both sensing and actuating are demonstrated. To restrict access to the sensor data and control over actuation, a HTTP digest authentication is used by the gateway node. The client machine view of the HTTP form for the speed measurement and control application is given below.

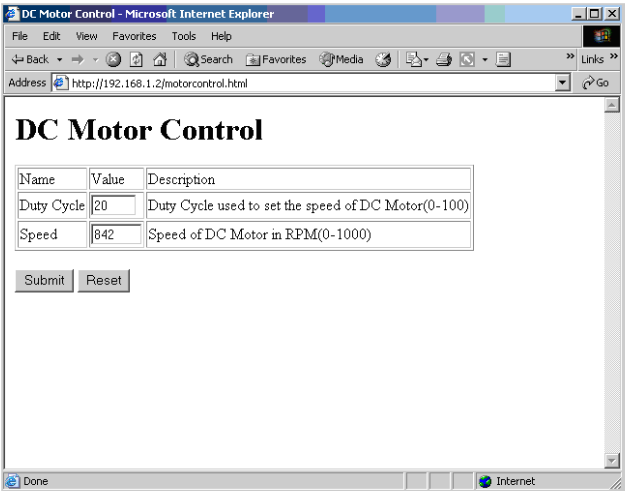

Figure 8. Speed monitoring and control form in client

V. IMPLEMENTATION OF POWER CONTROL ALGORITHM IN PICSENSE

A. *Introduction*

The implementation of power control Medium Access Control algorithm has been reported to demonstrate the usage of PICSENSE testbed for the empirical studies in transmission power control in wireless sensor networks. Though, lot of transmission power control algorithms are reported for wireless ad hoc networks, few empirical studies [5, 8] are reported in this area in wireless sensor networks. By exploiting the power of ADF7020-1 to change the transmission power level in 63 levels from -20dBm to +13dBm, an Optimal Power Control (OPC - MAC) has been developed in the PICSENSE node.

B. *Optimal Power Control MAC*

This OPC –MAC is an extension of CSMA/CA with RTS/CTS. OPC –MAC includes the adaptive transmission power control without using separate control channel as in Power Control using Dual Channel (PCDC) [6]. In a simple CSMA/CA protocol, the node senses whether the medium is idle or not. If the medium is idle, then it can do the transmission of RTS. After getting this RTS control packet the intended receiver sends the CTS. These RTS/CTS control packet flow is to avoid Hidden and exposed terminal problem which is prevalent in wireless MAC.

In OPC –MAC proposed here, the adaptive transmission power control is included as below.

I. Sender node senses the carrier. If it is idle, it sends the RTS at the Maximum power (+13dBm)
II. While receiving the RTS, the intended receiver measures the RSSI by which it can measure the range (d) approximately.
III. If the RSSI value is more than the RSSI threshold value then the optimal transmission power for the receiver is chosen by using the empirical channel model (equ. 3) implemented in the nodes.
IV. The power level is increased to an extent to compensate for the indoor attenuation factors Then the receiver sends CTS to the sender with the estimated optimal power and this packet contains the power level at which the receiver transmits.
V. Sender also changes its power level and do the data packet transfer at reduced power which depends upon the range between the transmitter and receiver

This kind of power control not only alleviates huge power consumption but also the interference problem and facilitates the spatial reuse of the channel. Here the RSSI threshold value is selected as -75 dBm which is well within the connected Region.

C. *Empirical Radio Model*

To calculate the optimal transmission power, a simplified model for path loss as a function of distance is used in every node [6].

$$P_r = P_t K\left(\frac{d_0}{d}\right)^{\gamma} \text{ -------------------- (1)}$$

Where

P_r = Received signal power

P_t = Transmitted signal power

K = path loss constant

d_0 = Reference distance for the antenna far field.

d = Distance between communicating nodes.

γ = Path loss exponent

$$K(dB) = 20 * \log_{10}\left(\lambda / 4\pi d_0\right) \text{ ---------- (2)}$$

An experiment has been done using two nodes. By varying the distance between the nodes, RSSI values have been noted down. By using these empirical data, channel model has been done.

The resultant empirical model is

$$P_r = -25.18 P_t \left(\frac{1}{d} \right)^{7.413} \qquad \text{-------} (3)$$

As per OPC-MAC, RTS is transmitted at maximum power (Pt = +13dBm) and RSSI is measured in the receiver (Pr). By substituting the Pt, Pr values, the approximate distance (d) between the nodes can be found. Now the optimal transmission power (Pt) can be calculated by substituting the RSSI threshold value for Pr and the calculated distance (d) in the above expression.

D. Results

The OPC - MAC was implemented in the PICSENSE wireless sensor nodes. In this MAC implementation, power level of the radio transceiver is reduced to a level to maintain the optimal link quality.

The experiments were done with two nodes and the energy consumption comparison between the CSMA/CA with fixed power and the OPC -MAC has been done. The power spent by RF transceiver is calculated from the Power Amplifier settings of transceiver by referring to the RF transceiver's data sheet. By referring to the ADF7020-1 data sheet [7] the power consumption in various transmission power levels are interpolated. The Optimum Power Control (OPC) MAC has been implemented in two nodes and the experiment has been done by changing the distance between two nodes.

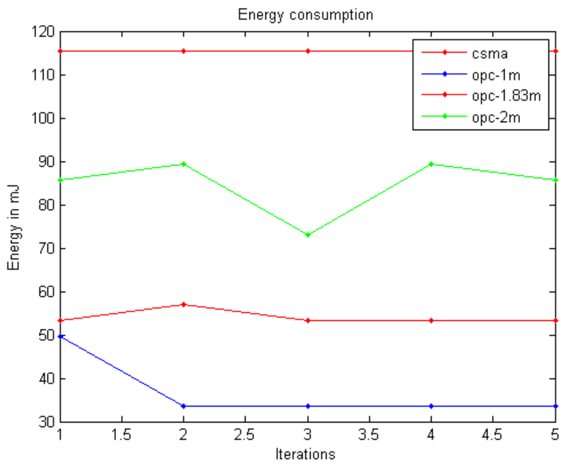

Figure 9. Energy consumption per single byte Data

The Figure 9 shows that the energy consumption of OPC MAC outperforms the fixed power CSMA protocol. And it is also shown that the energy consumption is dynamically changed according to the quality of the link between nodes.

VI. CONCLUSION

This paper reports about the design of the PICSENSE wireless sensor network testbed. The integration of the wireless sensor networks with the IP networks has been done using Rabbit gateway nodes. Most of the testbeds reported in the literature, use commercial gateway nodes like stargate which is not as flexible as the Rabbit gateway nodes. The firmware in the Rabbit gateway nodes can be designed to make the configuration of the gateway node either as a HTTP server or a FTP server or a simple router. The design of the firmware for the sensor nodes and that of the gateway nodes are discussed. The temperature sensor and speed sensing and controlling arrangement have been interfaced with PICSENSE nodes and the applications are developed for remote sensor data monitoring and control. To demonstrate the usefulness of PICSENSE testbed for empirical analysis of protocol research, a power control algorithm has been developed

In future this sensor network testbed can be upgraded with remote programming/debugging from the client machine in the IP networks and remote nodes' energy measurement so as to enable the user to access the testbed from remote location.

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