Novel design and performance analysis of WSN node using NRF and ATmega328

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Abstract—Designing an efficient wireless sensing network (WSN) node over a remote location is a challenging task in the heterogeneous environment. The two implementation challenges are – first, large distance with comparatively signal coverage and second, power consumption for devices. It is observed that the use of energy harnessing techniques by the research community has proven successfully redemption in power consumption for circuits involving antenna, microcontroller and sensor. In present work, a novel schematic design of a low power wireless sensing node has been discussed which is used for connecting different sensors such as moisture and temperature sensor. The design considered the wireless sensor node with a power module, a NRF, an Atmega-328 microcontroller and a GSM module to upload data over the cloud. NRF facilitates long-range communication up to a range of 1000m by using a maximum current consumption of 15mA. The wireless sensor node are key elements in implementing Internet of Things.

The performance in terms of power consumption is analyzed for long range communication. Experiment has been designed to transmit with an interval of 15 sec and interval of 60 sec. At the receiver end, the central node GSM sim800A module is used to upload data over the cloud platform Thingspeak. In comparative study with different microcontroller development boards & wireless methods it has been found that the designed WSN node is effective in saving power consumption. The node can act as master or slave and can communicate with several other nodes also.

Keywords: Wireless sensor network(WSN) node, NRF, Design, microcontroller, GSM, Internet if things (IoT).

I. INTRODUCTION

The wireless communication has helped the world to transmit data from remote locations. After development of amplitude modulation, frequency modulation and digital modulation techniques, it is possible to achieve a greater bandwidth at a faster data transfer rate. Advancement in communication technologies such as 4G and 5G has made easy the implementation of the Internet of things (IoT) and machine to machine interface (M2M) [1]. These technologies use frequency bands which need to get licenses, are expensive to use and devices are costly to transmit data. It has drawn the interest of researchers to develop wireless sensor nodes and networks [2, 3] which may not require licensing or purchasing the transmission on these bands. In WSN major functional block is sensor node which senses a physical property, collect data, and then transmit the information wirelessly [4, 5]. The major problem with the WSN systems is power. It is powered by a battery which needs to be charged or replaced from time to time. WSN nodes are placed in a harsh environment where it is not possible to change batteries [6-8]. Energy can be harvested using suitable techniques, from the surrounding environment [9]. Since the energy harvested is quite small, the power consumption of the WSN must also be maintained at a lower value. This highlights a need to come up with a newer method of designing a WSN node having low power consumption [10]. The factor of power consumption is important for a WSN node designer.

Sensing, processing, and transmission are three major activities of WSN node [11, 12]. A sensor node for monitoring air quality has been designed using the Arduino Yun development board in which the power consumption at the node was also observed [13]. The node relied on power harvested by a solar panel which was stored in batteries. The set-up was stipulated to run for days but due to adequate power consumption, a need to recharge again and again was highlighted. Rohit et al [14] used Raspberry Pi for designing an IoT based home automation WSN model. A critical limitation in their model was the need for a regular power supply thereby proving its inefficacy in running on battery sources. In similar lines, authors have also developed a sensor node for deployment in an infant incubator, however, since it was not wireless it consumed a significant amount of power [15]. Al-Haija et al. developed a WSN based system using arduino and gas sensors to monitor the air pollution. This system provide real time data of the concentration of various gas contaminants exist in air [17]. They have used wifi...
technology to transmit the observed data by the sensors over a long distance. The usage of Wi-Fi has been increased but due to power consumption during wifi transmission, the node life time has been affected [18]. Verma et al. has made use of Raspberry pi and wifi technology to develop home automation systems using a home network through which the home appliances can be accessed from any place the world. A script has been written in php for web portal in which the the user controls the appliances by giving some input. Python language has been used to configure the Raspberry pi [19]. Literature survey reveals that the most of the WSN node are designed on development boards with libraries available for programming. The power consumption performance parameter is ignored in most of the designed nodes. A comparative analysis of different systems has been done with the proposed system as represented in Table 1.

Table1: comparison with existing system

| Sl. no. | System existing/proposed | Features | Remarks |
|---------|--------------------------|----------|---------|
| 1       | Existing system[19]      | Iot for home automation, raspberry pi | Cost of hardware is high, wifi power consumption not studied, range is very low in few meters. |
| 2       | Existing system[18]      | System for ambient monitoring, a low power node has been designed. Based on Psoc. | The usage of Wi-Fi has been increased. The node life time has been affected with increase in power consumption. Low maintenance with self calibration. |
| 3       | Existing system[16]      | Vehicle pollution monitoring system developed using ESP 8266 with wifi. | Power consumption for sensor node is not studied, consumes a lot of power due to wifi and no use of sleep mode. |
| 4       | Existing system[14]      | System designed for home automation using raspberry pi connected to wifi. | No power consumption studied. Cost of one node is high |
| 5       | Existing system[15]      | Infant incubator system developed using arduino. Sensor node for temperature and pulse detection. | a sensor node for deployment in an infant incubator, however, since it was not wireless it consumed a significant amount of power |
| 6       | Proposed system          | WSN node, can be used for IoT, novel design, Range upto 1000m and remote data access. | Data sent over server and action taken based on analysis, can be used with many types of sensors. Node life has been increased, NRF communication & GSM in sleep mode help to reduce power. |

II. PROPOSED SYSTEM

We have designed a new WSN node with low power consumption and small size. The designed node can act as transmitter or receiver. The circuit can easily be connected to sensor giving output on single pin in analog or digital form. Fig. 1 shows power consumption takes place during transmission. The consumption, however, varies directly with the amount and the distance up to which data must be transferred. Out of all units, transmission unit require maximum power. We observe the power consumption in two cases. First the sensing data is sampled after every minute and then data is sampled after 15 seconds, the consumption changes quite drastically. Power consumption is also affected by the communication protocol used to transmit data.
FIG. 1: Power usage in a Wireless sensor network node

HARDWARE & SOFTWARE DESCRIPTION

Atmega-328 is an AVR family microcontroller with 28 pin DIP. It has 6 analogue inputs and 13 digital input/output pins. A high-performance Microchip power in pico-watts 8-bit AVR RISC-based microcontroller combines 32KB ISP flash memory with read-while-write capabilities. It has a 1024B EEPROM, 2KB SRAM, 23 general-purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts. It also has a serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, a 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts.

NRF24l01 is a single chip trans-receiver working in frequency of 2.4-2.4835 GHz ISM band. It is embedded with a baseband protocol engine known as Enhanced ShockBurst. It is generally used for low power wireless applications. Its maximum current consumption is 15mA. It can be operated using SPI (serial peripheral interface) using Master Out and Slave In(MOSI) and Master In and Slave Out(MISO) pins as shown in figure-2. The frequency channel, output power and the data rate can be configured depending upon the need. It supports a data rate of 250kbps, 1Mbps and 2Mbps. Overlapping channel spacing is 1 MHz and 2 MHz. A single NRF module can connect with six (6) others modules as the transceiver. We can create a network of more than 3000 nodes using tree topology of 5 levels deep as shown in figure-8. Each node is assigned with address in the octal format defined by 15-bit address.

Fig. 2: NRF24l01 module pin diagram.[30]

The SIM800A is a Quad-Band GSM/GPRS Module working on RS232 interface. It is a GSM/GPRS solution in an LGA(Land grid array) type which can be included in applications. SIM800A support Quad-band 850/900/1800/1900 MHz, and it can transmit voice, SMS and data information with low power consumption. It is very small in size of about 100 x 53 x 15 mm and it can fit into slim and compact pcb designs for customized products. It features AT commands and also have embedded module to process the same. It allows total cost savings and fast time-to-market for customer applications. RS232 interface enables easy connection with the computer or laptop by using a USB to the Serial connector, or to the microcontroller using the RS232 to TTL converter. When the SIM800A modem is connected using the USB to RS232 connector, it is assigned a COM port number from the Device Manager of the USB to Serial Adapter.

ThingSpeak is an IoT analytics platform service that allows users to aggregate, visualize, and analyze live data streams in the cloud. Additionally, users can send data to ThingSpeak from their devices, create instant visualization of live data, and send alerts. It provides RESTful and MQTT APIs

CIRCUIT DESCRIPTION

The system is composed of a transmitter and a receiver section. At the transmitter, the sensed value is converted into
digital form using microcontroller which is further transmitted by using the NRF module. The system is powered by 3.6volt 2600mAh Li-ion battery cell which is rechargeable. Single transmission of data uses 30mA current and 3.3V to 5 volt supply. Maximum power dissipation by the circuit is 45mW+75mW. The current work focuses on the design of the sensor node. At the terminal, any type of sensor which can give output using only a single pin can be connected. Therefore, temperature and moisture sensors are connected in this terminal.

Block diagram of the system is shown in figure-3. It consists of two section transmitter and receiver. Transmitter node of the system is shown in figure 3a and the receiver node is shown in figure 3b.

![Figure 3: Block diagram of the system a) Transmitter node b) receiver node](image)

Circuit design and PCB schematics are obtained as shown in Fig.4 - 5. Eagle software has been used for PCB schematic and CNC routing & drilling machine has been used for PCB printing. Eagle for board design helped to stack components in a compact space as per preferable dimension. It traces the connections through copper and idealized the design onto the PCB. Fig. 6 shows the PCB after having the components soldered. The size of the PCB is approximately 5cm in length and 4 cm in breadth. Height is around 3cm.

![Figure-4: Schematic of circuit designed in Eagle software. Figure-5: PCB schematic before printing.](image)
Figure-6: Actual image of the sensing node after mounting components, attaching power module and NRF antenna.

III. WORKING OF PROPOSED SYSTEM

We have designed two systems, first the sensing node with transmitter NRF and second the receiving central node which collects the data from all sensing nodes and can upload the data on the cloud. The central node will also process the parameter. Whenever the microcontroller is powered up the program which is loaded in the memory is fetched by the processing unit and executed sequentially according to the algorithm displayed in Fig. 7. After data gets captured using the sensors, the value converted by microcontroller ADC (analogue to digital converter) is pushed onto the radio network using NRF24L01 module. NRF uses the SPI communication protocol to get and send the data from the microcontroller. The network for 2 or more sensing nodes may be arranged using the tree topology. Each NRF node can communicate with maximum 5 nodes in the hierarchy. The address of nodes is defined in the octal form with base address 00 given to central receiver and 01-05 for the first layer nodes as shown in Fig. 8. The addressing is continued for the successive nodes.

Results:
The experiment for transmission of one sample of data is conducted using the designed WSN node and the observations are recorded in the table below.

### Table 2: Power consumption details of the components

| Mode of operation | Atmega-328p | NRF24L01 | GSM-SIM800A |
|-------------------|------------|----------|-------------|
|                   |            | current  | voltage     | current | voltage | power    | current | voltage | power    |
| Sleep             | 23 µA      | 5V       | 115 µW      | 0.026   | 3.6V    | 93.6 µW  | 2 mA    | 3.3 V   | 6.6 mW   |
| Active            | 45 mA      | 5V       | 225 mW      | 13.5 mA | 3.6 V   | 48.6 mW  | 350 mA  | 3.3 V   | 1.155 W  |

The sensing node is powered by using rechargeable Li-ion battery of 2600 mAH. Ampere hour is the amount of charge stored in the battery. Since a battery changes voltage during the discharge, it isn’t a perfect measure of how much energy is stored and we would need watt hour. Multiplying the average battery voltage times the battery capacity in amp-hour gives you an estimate of how many watt-hours the battery contains.

\[ E = C \times V_{avg} \]

\[ E \] is for energy in watt-hours, \( C \) is for charge in amp-hours, and \( V_{avg} \) is the average of voltage.

If the current drawn is \( x \) amp, the time is \( T \) hours then the capacity \( C \) in amp-hours is

\[ C = xT \]

Current required by sensing node during one transmission = 30 mA
Current required by the central node with GSM= 330 mA.
Total number of hours battery cell can power sensing node= 2600 mAH/30 mA = 86 Hrs
Total number of hours battery cell can power central node with GSM= 2600 mAH/330 mA = 7.8 Hrs
We will be using 2 battery cell for central node, one to power the NRF and microcontroller and other to power the GSM.

Comparison of sensing node power consumption using Atmega328P on customized PCB, arduino and NODEMCU.

| Parameter          | Proposed design (with NRF) | Arduino (with NRF) | Node-MCU (with wifi) |
|--------------------|-----------------------------|--------------------|----------------------|
| Operating voltage  | 3.3 to 5 V                  | 3.3 V to 5 V       | 3.3 to 5 V           |
| Current consumption| 30 mA                       | 50 mA              | 80 mA                |
| Range              | 1000 m                      | 1000 m             | 100 m                |

Another comparison of power consumption by PSoC-BLE during active & sleep mode is also analyzed and shown in Fig. 9 with the help of CRO. It is found that in the active state the current consumption peak is 100 mA, whereas, in the deep-sleep state the current consumption is in few \( \mu \)A. In comparison with the NRF module, the range of BLE is in few meters which restrict the usage of BLE over a long-range.

Fig. 10 show the noise with the signal. The markers are added in CRO and the minimum value of the signal is 3.0436 \( \mu \)A and the maximum value of current in the signal is 6.552 \( \mu \)A. The noise signal range...
span is about 3 µA. the figure also shows the average, RMS, peak to peak and other parameters in the measurement panel in the lower part of the screen.

![Figure 9. Both sleep current & active current measurement are required for power consumption reduction.](image)

The analysis is continued further for observing the fast Fourier transform of the noise signal, the result of which is shown in figure 11. The hardware setup for PSoC-BLE is also shown for the reference in figure 12.

![Figure 10. Example of signal hidden with the noise with peak to peak value of 3.516 µA](image)
Conclusion:

A low power WSN node has been designed using Atmega328P and NRF technology to develop a network of wireless nodes for monitoring data. The nodes can be deployed for a long duration of time and with solar can sustain for days and weeks. The experimental result shows that power consumption is low. The paper is restricted to the design of WSN node and avoids the discussion on the communication protocol. The network is expedient, uncomplicated, and consumed less time to set up. The experiment justifies that power consumption of the whole network has been reduced significantly, and additionally verifies the effectiveness and energy-saving capability of the design. Comparing different module for IoT wireless sensor node for long-range communication, the developed WSN node is most suitable in power
consumption and can go in sleep mode as per the design. The size of the PCB developed is also quite compact & of low cost in comparison to development boards. The designed node discussed in the paper can be installed at a remote location with connectivity in a range of kilometres. The range can be extended by using the tree topology. The nodes can be deployed for a long duration of time while maintaining power consumption to a low value.

The power consumption is tested and verified experimentally. Experiments show that the designed wireless sensor node has the following characteristics.

1. Low power consumption, good stability, battery power can work for 86 hours without charging at transmitter side and 7.8 hours on single cell at receiver side with GSM module.
2. Transmission need not to be directional and distance can be increased (typical single node range is 1000m), any placement detection location, to achieve any time and space scale detection.
3. Can achieve multi-hop routing.
4. Scalable according to the specific need of sensor mounted.

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