A Practical Study on Building a Wireless Sensor Network

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ABSTRACT

Recent developments in wireless communication and electronic devices made it possible to make low cost and small sensor nodes. These nodes can measure, store, process and transmit wide range of physical parameters, and then communicate these measurements with each other and/or with an external Base Station (BS). A Wireless Sensor Network (WSN) is composed of a number of sensor nodes that are randomly or manually distributed inside or around the phenomenon (or sensor field). Indeed, WSNs have wide range of civil and military applications. In this paper, we design and build a functional model of a sensor node. We outline our design and implementation methodology and then demonstrate the use of such sensor nodes in some useful real life applications that include light and temperature control, and dynamic traffic light control. This last application is currently being commercialized to replace existing and expensive models. The paper is concluded with some future highlights and useful remarks.

Key Words: Wireless sensor networks, design and implementation, sensor node, applications.

1. Introduction

People's challenge is always directed toward maximizing their space of freedom. Hence, they always try to replace any fixed or traditional systems with other more flexible and easy to use ones. One example is the use of new technologies toward monitoring and control of many environments in a manner that reduce human interference, automate the process, and increase levels of security. Wireless sensor network announces that it is the perfect solution for monitoring and control of many environmental phenomena. *Wireless Sensor Network* (WSN) is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it [1]. The position of sensor nodes need not be engineered or predetermined. Hence random deployments in inaccessible terrains or disaster relief operations are possible. On the other hand, sensor network protocols and algorithms must possess self-organizing capabilities as WSN normally lack communication infrastructure. Moreover, WSNs can be used in different environments with hard conditions such as deserts, forests, highways, roads, or even in large factories. In most of these applications, the network must maintain full connectivity over the sensor field such that in case of failure of any node, other nodes must rearrange themselves to restore or maintain the functionality of the network (see Fig. 1 for WSN architecture.). A wide variety of ambient conditions, e.g., temperature, humidity, light, pressure, noise levels, the presence or absence of certain kinds of objects, speed, direction, and size of an object can be measured by a sensor node [2]. In fact, the applications of WSNs can only be limited by imagination.

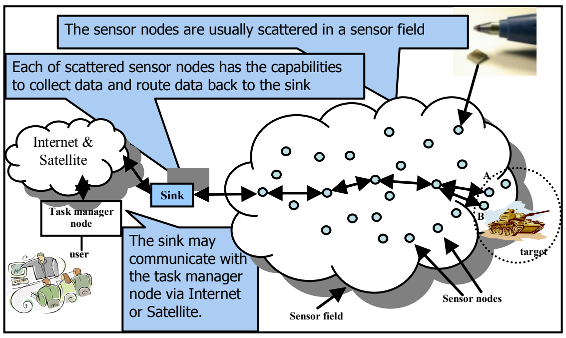


Fig. 1: Wireless Sensor Network Architecture

One important aspect of WSNs is that sensor nodes are normally powered by a non-replenishable energy source. As such, power efficiency is an important issue in the design of WSNs. Also, sensor nodes are fitted with an onboard processor, which can locally carry out simple computations on raw data before sending it to other nodes or to the base station (BS). The overall organization of the sensor node is shown in Figure 2.

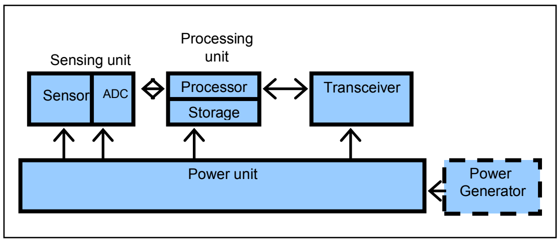


Fig.2 The organization of the sensor node [1].

Due to the large number of WSNs applications, we were motivated to design and build simple and functional WSNs. The basic unit of WSNs is the sensor node. Due to limited availability of modern VLSI tools in the country, we decided to build the sensor node using of-the-shelf components. Our objective is to build high speed and low cost WSN that can adapt wide variety of applications. In this paper, we report on our experience in designing, building, and implementing a model for sensor nodes. We then demonstrate the use of such sensor nodes to build WSN for real life and practical applications. The most important of these applications being the traffic light control application. In this application, the traffic light durations can adapt dynamically to the road traffic conditions. When compared to existing solutions for such application, our solution is more efficient and far less expensive. Furthermore, due to lack of infrastructure, we had to implement our dedicated routing protocol to handle the communication between these sensor nodes and at the same time realizing power efficiency in the network operation.

The rest of this paper is organized as follows. Section 2 briefly describes the design methodology and implementation of the sensor node and compares it to some existing designs. In section 3, we describe some applications that were built using the sensor nodes that we build to demonstrate the efficacy of WSNs. Finally, Section 4 concludes the paper and highlights some future directions.

2. Design Methodology

Our design uses of-the-shelf components. In order to build a functional model of sensor nodes, each sensor node is divided into four main units (see Figure. 2) [3]:

1. On-board Sensors
2. Processing and storage (MCU)
3. Communication (RF TX/RX)
4. The power unit.

Browsing through the market, we tried to select suitable components to build the sensor node. Our search resulted in the following components:

1. On-board Sensor requires about 1 to 10 JD and this depends on the type of sensors chosen; photocell sensor, temperature sensor, motion detection sensor and pressure sensor. We select most of them to be used in our WSNs Applications. (See Figure.3).

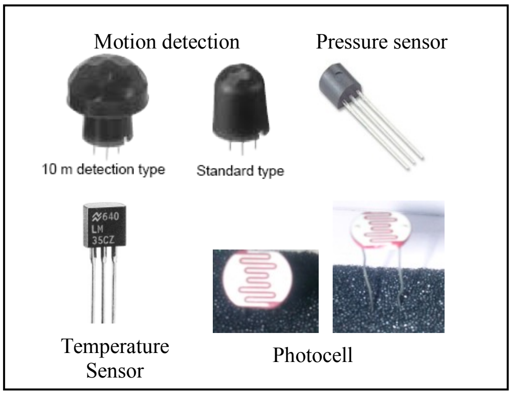


Fig.3 On Board Sensors

2. Processing and storage (e.g., microcontroller) requires about 8 to 10 JD, and we choose the Microchip PIC controller 16F877 for its simplicity and rich functionality (see Figure. 4).

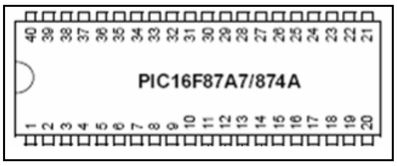


Fig.4 Microchip PIC 16F877 Microcontroller [6].

3. Communication (RF TX/ RX) requires about 20 JD for AM transceiver module, and we choose Aural AM Transceiver module that operates on 433MHz which is the least expensive and fits the purpose (See Figure.5).

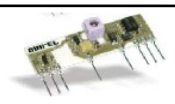
TX-4MSIL Transmitter	AC-RX Receiver
	

Fig. 5 AM Aural Transceiver Module [7].

4. The power unit, cables, amplifiers, transistors etc… requires about 5 JD, and we choose to use both DC adapters and 9V Lithium battery.

Using the sensor node components we have chosen, we build a completely functional model for the sensor node. Figure.6.a shows our sensor node design, and Figure.6.b shows the real implementation of our sensor node design. This design has been thoroughly reviewed and tested.

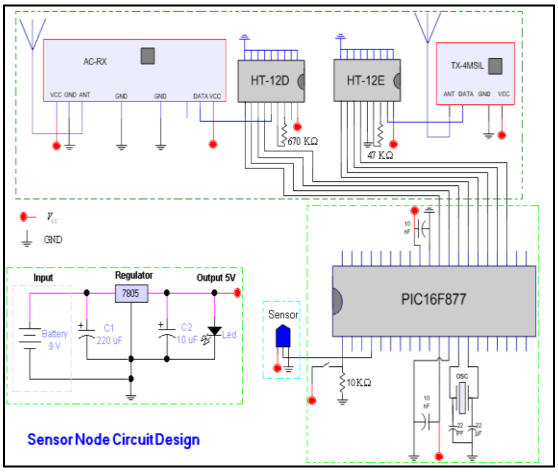


Fig. 6.a Sensor Node Circuit

Compared to other existing designs, e.g., Smart Dust, Berkeley and MICA Mote [3,8]. Table 1 summarizes this comparison. As the table shows, our design is better than the design of WINS NG 2.0 for most of comparison parameters, e.g., the cost of the sensor node.

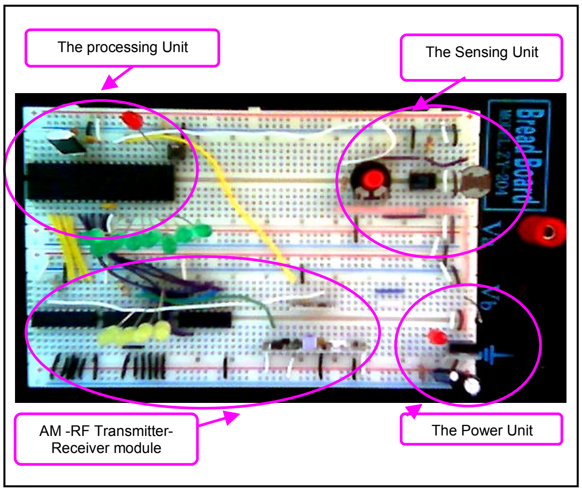


Fig. 6.b Implemented Sensor Node

	Smart Dust	*Berkeley MICA Mote*	*WINS NG 2.0 Node*	*Our Design*
Parts cost (quantity 1000+)	<$1	$ 10s	$ 100s	$ 70 (50 JD)
Size (cm3)	0.002	40	5300	240
Weight (g)	0.002	70	5400	100
Battery Capacity	(Less)	15 (KJ)	300 (KJ)	350 (KJ)
Sensors	MEMS sensors to be integrated	Acceleration, temperature, light, and sound	Off-board	Light (photocell Sensor) integrated on bread board
Memory	(Less)	4 KB RAM, 128 KB flash	32 MB RAM, 32 MB flash	368 × 8 byte RAM, 8K × 14 byte Fash
CPU	(Less powerful)	ATmega 103L	Hitachi SH4	Microchip
Operating System	(Smaller)	TinyOS	Linux	MikroBasic
Processing Capability	(Less)	4 MIPS	400 MIPS	4 MIPS
Radio Range	(Shorter)	30 m	100 m	Above 150 m

Table.1 Comparison between sensor node designs [9]

For the sake of building a simple, useful, and multipurpose WSN, we have built five sensor nodes of the one described above. These nodes were also equipped with various types of sensors to handle variable applications. The code written for these applications uses MikroBasic programming language including the routing protocols [10]. In the next section, the applications of Temperature monitoring application, Light Control application, and Dynamic Traffic Light control application are presented in details. Many difficulties were faced in this work. We summarize some of them below:

- *Data synchronization:* in order to receive data correctly, send and receive should be synchronized. This problem was solved by programming the microcontroller using the MikroBasic, which provides the ability to control the time between the sending data and the receiving data precisely.

- *Noisy received data:* the noise in the received data was eliminated by using an external Encoder and Decoder chips.
- *Weakness of the received signal:* the received signal was weak; so the microcontroller can not know if it's one (High) or zero (Low); so the solution was to use a buffer to amplify the signal.
- *Transmission and reception range:* to get the large range between the sensor nodes to communicate with each other, two solutions are applied; the first one, using a receiver with high sensitivity power (greater than -100dbm) in order to achieve a higher range more than 100 m. The Second one was to use a half dipole antenna with 50 ohm matching impedance.
- *Circuit Protection and Stability***:** to protect the circuit from faults in the connections, a robust power supply circuit is built to block the current from harming the circuit in case of wrong connections.

3. Applications

We demonstrate the use of the sensor nodes in some real applications as follows.

3.1 Light monitoring application

For the Light monitoring application, we use two sensor nodes to demonstrate the communication between the sensor nodes. We configure the two sensor nodes to be event driven such that the two sensor nodes are placed in two different places within the communication range of each other. Each senor node is equipped with a photocell sensor with adjusted light sensitivity. When a light is detected by one sensor node, it will send a signal to the other sensor node for some action to be taken (see Figure 7). This simple scenario can act as the basic building block for many control systems that depend on light control, e.g., home automation regarding light control.

One important issue here is how to handle communication when nodes are operating on the same frequency especially if two or more sensor nodes try to transmit to the wireless medium at the same time. Interference will occur and harm all the transmitted signals. In order to overcome this problem, a careful time scheduling was followed and implemented.

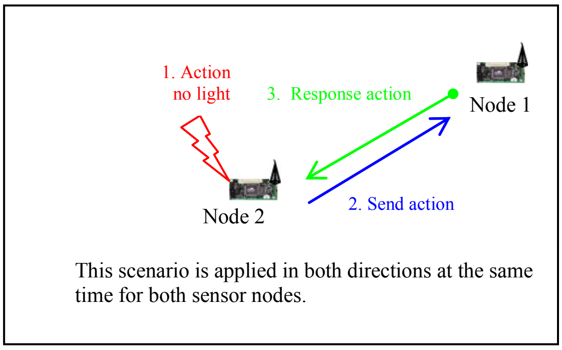


Fig. 7 Light Monitoring Application Communication Scenario

3.2 Temperature Monitoring Application

In this section, we describe the scenario we have applied to monitor the temperature in a certain area and we have chosen the Faculty of Engineering building in our university to study the temperature circumstances. Figure.8 shows the architecture of the temperature application used.

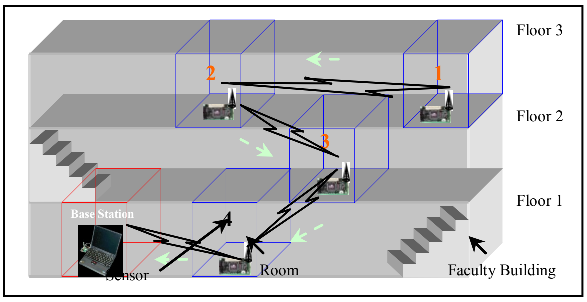


Fig. 8: Temperature Control Architecture

First, we distribute four sensor nodes in several halls in a three floors of the faculty. Node 1 and node 2 were placed in the third floor, node 3 in the second floor, while node 4 and the base station sensor node were placed in the first floor.

- The temperature readings were collected all the day every five minutes from the various distributed sensor nodes in all the three floors. The readings were collected from 9 AM to 4 PM.

- All the temperature readings were collected by the sensor nodes which by its turn transmitted these readings to the base station.
- The base station sensor node which is connected to a computer, store the readings as a database, which can be retrieved by the user and make use of it, the graphical user interface is made using Visual Basic.Net and the data stored using MS Access data base.

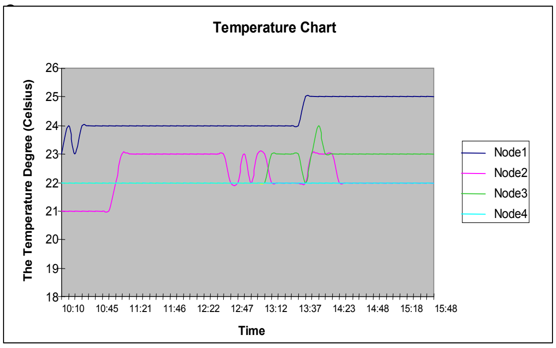


Fig. 9: The Temperature Monitoring Chart

Figure.9 shows one of the experiments that have been done and the temperature collected readings. From Figure.9, it is obvious that the temperature readings of node 4 didn't change over the test period. This is because node 4 was placed in a laboratory with air conditioning, which by itself regulates the temperature to fixed value.

The routing protocol used in this application is a static routing protocol. In this type of routing protocols, every time the source node wants to send its data to the base station, it will use the same route to reach it. So, the base station needs not to be within the transmission range of the source node. The advantage of this routing scheme is that it achieves a very large coverage and sensing area using minimum number of sensor nodes. See Figure.10 that demonstrates this scheme of routing. In our application we use this type of routing as follows:

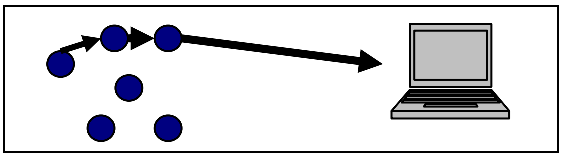


Fig.10 Static routing protocol

- Node1 will transmit its data to node 2.
- Node2 will transmit node 1's data to node 3
- Node3 will transmit node 1's data to node 4 and
- Node4 will transmit node 1's data to the base station. After that the same matter will happen to Node 2 data;
- Node 2 will transmit its data to node 3 which in turn will transmit this data to node 4 then to the base station.
- Also, node 3 will transmit its data in the same path to the base station, and then node 4 will do so. See Figures 8 and 11 that demonstrate this path and the topology.

The static route is used in this application to cover large area, this mean that each node do not need more than one node to be in its transmission area to communicate with the base station, so large area will be covered using this route technique. In summary, the data collected from the four nodes will be stored in the base station, and then the difference in the temperature between the halls and the change in the temperature of the same hall can be observed all the day.

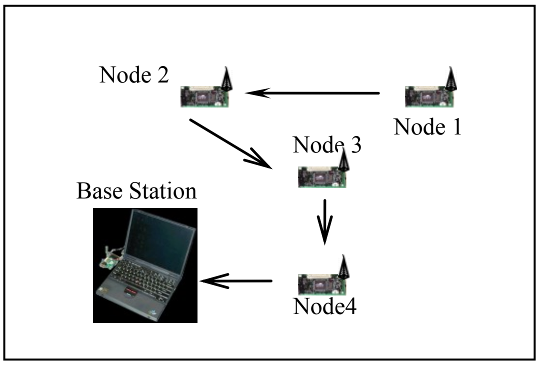


Fig.11: Temperature Control Topology

3.3 Dynamic Traffic Light Control Application

This kind of applications is introduced to solve a real time problem; this problem is the traffic light congestion that arises due to the fact that all traffic lights on streets, will take the same time weighting for the traffic light to switch green for cars to be able to move.

The traffic light control application is introduced to control the periods where the traffic light is green or red. The traffic lights will be controlled depending on the number of the cars in each traffic light, this means that; if a traffic light has two cars waiting for the traffic light to be green, while another traffic light has five cars waiting for the traffic light to be green, then the first traffic light will have short period of time when it's green in compare with the second traffic light. Let's see the application architecture.

Four sensor nodes are placed under ground. Each one of the sensor nodes is connected to motion detection sensor that is used to count how many cars will pass over it. This process will happen only when the traffic light is red. Figure.12 shows this architecture.
The scenario of this application is based on that each sensor node will send its data to the base station, which by its turn will control the work of the network according to the various information collected from the sensor nodes, and then sends to each node what it should do i.e. when to be green and when to be red.

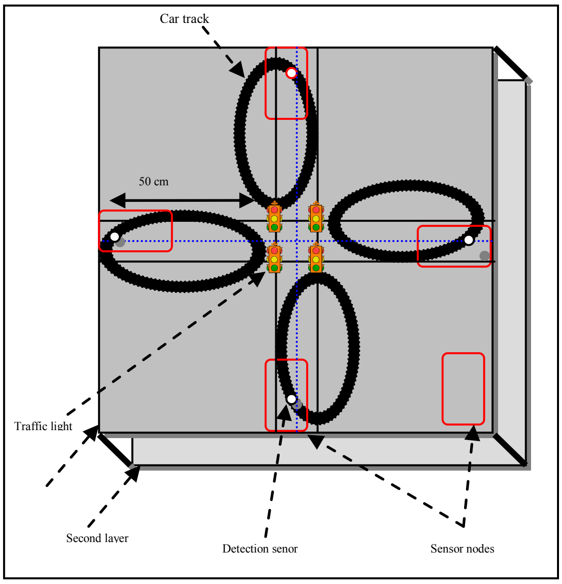


Fig.12 Traffic Light Control Architecture

Here in this application, we also use a broadcast route; each node will communicate directly with the base station. This is called non-cooperative routing. In this scheme of routing, the base station must be in the range of the transmission area of each node.

Each sensor node will send the number of cars that pass over the detection sensor, when the traffic light is red, to the base station. The base station will compare the received numbers of cars from the sensor nodes to form a proportional factor by which will determine how much every sensor node would turn on red and green.

Figure.13 demonstrates how the transfer of data will be between the base station and the sensor nodes.

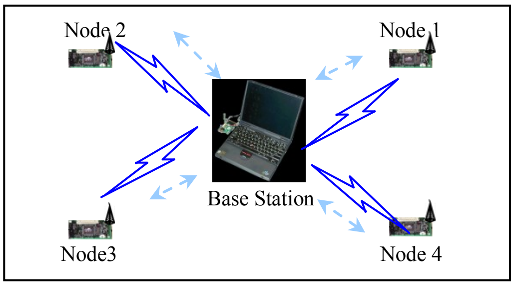


Fig.13: Traffic Light Control Topology

4. Conclusions

In this paper, a real wireless sensor network was designed and implemented. The network built was also demonstrated using many applications. Although the design is simple and uses of-the-shelf components, it stands as a major contribution and a first step toward initiating a practical research field in Jordan. Despite of the difficulties and problems that we have encountered, the sensor nodes and the wireless sensor network were successfully built. The design can still be enhanced in many aspects, which is currently being investigated.

References

[1] Ian F. Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, & Erdal Cayirci, "A Survey on Sensor Networks", *IEEE Communications Magazine*, 102/114, PP. 0163-6804, 2002.

[2] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless sensor networks: a survey", Elsevier

Science B.V., 293/402, PP. 1389-1286, 2001.
[3] Seth Edward-Austin Hollar, "COTS Dust", Master Thesis, Berkeley, 1/5, 2000.
[4] Temperature sensor LM35DZ, http://farnell.com/datasheets/45181.pdf ,
[5] http://www.napion.com/; MP Motion Sensor datasheet.
[6] http://www.microchip.com; PIC-Microcontroller Datasheet,
[7] http://www.aurel.it ; AC-Rx Receiver datasheet and Tx-4MSIL datasheet.
[8] http:// www.kingkong.me.berkely.edu.
[9] FengZhao, Leonidas j. Guibas, "Wireless Sensor Networks: An Information Processing Approach", Morgan Kaufmann Publisher, 2004.
[10] MikroBasic Documentation Manual, www.mikroelektronika.co.yu.