A prototype for modular Sensor Network Testbed: CENSE

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Abstract. Sensor networks have become viable for a large variety of applications. But due to highly optimized nature of its nodes, it is not possible to have one solution for all the different kind of applications. This results in the need of a sensor node which is very application specific. For carrying out research and development in this area, it is important to have access to a sensor network testbed, which is flexible to suit the requirements of different applications and technological developments. We have undertaken development of a modular wireless sensor network testbed to cater to these requirements and have fabricated/tested prototype of the same. The nodes are modular and consist of power, processor, sensor and communication modules connected by an interconnecting bus. The improvement and optimization work is continuing. We feel that this testbed would permit a good platform for researchers working in this area. This paper briefly describes the various aspects of this testbed named 'CENSE', which is expected to have one hundred nodes.

1 Introduction

Technological improvements in sensing, processing and communication coupled with improvements in fabrication technology has made it possible to use "Wireless Sensor Networks(WSN)" in a wide variety of applications. They can range from disaster management to military espionages to weather monitoring. Many sensor networks have been successfully deployed in the field (GDI [1], ZebraNet Wildlife tracker [2]) The range of applications vary from scientific to military to environment monitoring [3]. Due to the optimization of cost, energy and size of sensor nodes, they are highly application dependent. In most of the applications, we need to go through a trial phase to understand the detailed needs of the application, before we can design an optimized system. This necessitates the need for a testbed for the development of wireless sensor network. We have undertaken this task, as a first step, to allow us to develop application of WSN.

Our WSN testbed 'CENSE' (A Century of Sensor nodes) tries to address this aspect of sensor networks by providing flexible modular platform for testing and optimization of nodes for Sensor Network applications. 'CENSE' currently provides for processing, communication, sensing and power modules but the design can be easily extended to add more modules like mobility and localization.

In this paper we present the capabilities of the testbed, its design, development, testing and current status. Section 2 deals with Design aspects, Section 3 is about Implementation details and Section 4 covers the Testing of our design.

2 Design

We would like to design a test bed which is flexible, cost efficient, easy to use, power efficient, provides excellent debugging facilities and covers all major requirements of sensors networks. Keeping these things in mind we have divided a sensor node in four modules depending on their functionality. Four modules that we have conceptualized are processing, sensing, power and communication. Justification for such division is that based on the application, we may need to change only one of the modules, while reusing the rest of the modules. To appreciate this point we give an example. Suppose we have a sensor node on the test bed designed for gas-leak detection application. If we want to change the node for micro-climate monitoring, the only part that needs to be changed is the sensor module. All other changes are only in software. Similarly a researcher wanting to optimize network protocol only needs to make appropriate changes in software to test the protocol performance. Design of 'CENSE' should be such that the modules of the testbed are independent of each other or have least interdependence. This would allow one to change any of the module without affecting the other. Thus we need to create a standard bus interface design for modules with matching interconnecting bus.

2.1 Requirements

We eventually propose to build a testbed consisting of 100 nodes for testing the applications so that we can have a sensor network setup covering sufficiently large geographical area, providing significant variations in the physical parameters of interest. Choosing number of nodes more than 100 would increase the cost, fabrication time and debugging difficulties, where as having lesser than 100 nodes would bring in the effect of boundary nodes more prominently. This would impact scaling of the result of the testbed to larger numbers. Secondly the nodes can be spread in a 10×10 matrix covering 1 square kilometer which is roughly the size of our campus. They would also allow us to implement and test multihop routing protocols. These requirements on the sensor networks, translate into capabilities of the individual nodes. So we now focus on the requirements of nodes. Here we will discuss requirements of four basic modules of a node and the interconnecting bus i.e we are not taking into consideration optional modules like mobilization and localization.

Power Module: This module needs to provide operating voltage to all the modules. Currently we have envisaged only one operating voltage but in future we may opt for one more operating voltage. The module may have provision for a energy scavenging source to keep battery charged. Module needs to provide information about the residual charge of the battery and the information related to energy scavenging source(e.g. solar panel).

Processing Module: This module has the general processing capability for the whole node, although there may be dedicated processors on other modules as well. It will typically run an OS and coordinate all the activities of the node (sensing, processing, communication). It will also control its own modes of operation at various times. This module requires digital and analog lines from sensor modules to get sensor data. It will also have digital link to communication module for receiving and transmitting information. There may also be control lines required from this module to other modules to control/configure their operation.

Communication Module: This modules has the analog RF front end as well as antenna for wireless communication. It has to be connected to the processing module through a digital link for data communication. The module may also need a analog/digital link to indicate received RF signal strength. This may also require some digital control line from the processing module for configuring the device.

Sensors Module: Typically sensors are packaged in two types, Analog and Digital. A separate dedicated analog line is required to connect each of the analog sensors. However many digital sensors can interface to a single bus, though they may need different buses like I^2C, SPI, USART etc. Since both analog and digital sensors can be present simultaneously, we need to have provision for both. Sensor board will be very application dependent and currently we are making only one sensor board to cover two applications namely microclimate monitoring and seismic wave monitoring. Later on we will design more sensor boards.

Bus: Main requirement from bus is to make the modules least dependent on each other. This is a strong requirement since we want to change a module without affecting the others. Modules may be operating on different voltage level, may use different output formats or they may have totally incompatible connectors. Therefore some constraints or rules would come in the system during the design of such a common interface. We have tried to make the constraints such that they dont become a hurdle in testing of node for most of the applications. Some design constraints that have to tackled are listed here (see *Table1*). We need to specify beforehand number of connecting lines to be used for a particular task, with nature of signals, maximum data transfer speed, maximum current capacity, operating voltage etc. These specifications would allow us to make the interface without missing any required features.

2.2 Solution

Before making any decision on any of the constraints, a literature survey was done to collect information from various vendors about microprocessor, sensors, power supply and communication devices. We found that a large set of microprocessors provide very similar interfaces like digital I/O, ADC, support for USART, I^2C,SPI and JTAG port. Next we found that almost all the sensors and communicating devices can be interfaced using these. It was also found that

Constraints	Value	Assumption
Wires or lines	40	leaving some extra line for future
Max Data rate	1Mbps	SPI has 1Mbps data rate and is the fastest bus
Max Current	100mA	worst case radio requirements are 300mW. Assume. Voltage =5V. I=P/V[4]
Power Supply	5V	most of the devices are compatible with 5v

Table 1. Constraints on the design

majority of the microprocessor and devices were compatible with operating voltage of 5V. The data thus obtained indicated that a lot of devices are compatible with each other in terms of operating voltage as well as input/output signal. This helped us in selecting the power supply output (see *Table1*), total number of lines required (see *Table2*), different types of digital buses required, number of analog lines required, maximum current that may flow in the line, max data rate to be supported by the interface.

Type of lines	Number required
Power	2
JTAG	4
I^2C	2
SPI	4
USART	3
ADC	8
Interrupt	1
Ground	7
Total	31

Table 2. Number of lines required

We have also tried to define our requirements by analyzing the requirements of various application. For example most of the application would not require more than 8 analog sensors. WSN requires short range communication, so we do not require powerful radios. Examples of applications we referred to include GDI habitat monitoring [1] , weather monitoring, countersniper system [5], object tracking [6].

3 Implementation

Two solutions which we considered for the interconnecting bus are based on Flexible Ribbon Cable (FRC) and Plug and Socket. Both the solutions can serve our purpose equally well. But the easy availability and low cost of FRC made it our preferred choice. The FRC has four FRC female connectors on it, which allows the modules to interconnect.

Both solutions may suffer from the electrical signal interference due to the high voltage or high frequency signal on the neighboring line. *Table3* shows the interference pattern observed in the FRC when different kinds of configurations were tested. *Figure 1* shows the pickup as observed on the oscilloscope. In the setup length of the FRC was 6 inches. We assumed that signal voltage would never increase above 5V, the maximum bandwidth would be 1 Mbps since the fastest bus we are considering is SPI, which works at this speed.

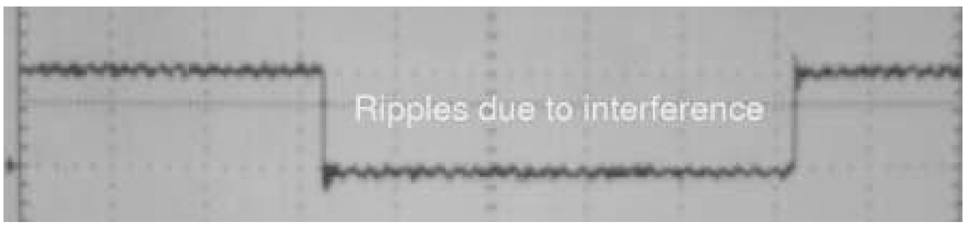

Fig. 1. Pickup as seen on digital line due to a adjacent analog signal line

Method	Signal Type	Pk-pk(V)	frequency	Effect on Neighbor
One line carrying digital signal, effect on neighboring	Square	5	1MHz	640mV square wave
One Analog Signal effect on neighbor	Sinusoidal	5	2KHz	same shape 372mV pk-pk
	Triangular	5	2KHz	same shape 324mV pk-pk
	Sinusoidal	5	200KHz	same shape 496mV pk-pk
	Triangular	5	200KHz	same shape 424mV pk-pk
	Sinusoidal	5	2MHz	same shape 496mV pk-pk
	Triangular	5	2MHz	same shape 424mV pk-pk
Effect on one digital line between two analog line.	Sinusoidal	5	20KHz	none
	Sinusoidal	5	200KHz	sine wave super impose on square waveform
	Sinusoidal	5	2MHz	freq. of sine wave increase on square waveform
Insertion of GND lines	Sinusoidal	5	2MHz	sine wave amplitude decreases
Effect on one analog line between two digital line	Sinusoidal	5	20KHz	none
	Sinusoidal	5	200KHz	sine wave superimpose on square waveform
	Sinusoidal	5	2MHz	freq. of sine wave increases on square waveform

Table 3. Interference/Pickup pattern in FRC

The maximum pickup found on the neighboring lines was 496 mV ($\sim$ 0.5V) due to a sinusoidal signal of 5V pk-pk in an adjacent line. This kind of interference would have little effect on the digital lines (digital high 5 - 3.5V and digital low 0 - 2.5V). However this may be a significant source of error in analog signals. So we placed alternate ground lines between the analog lines to reduce the interference as this was found to be effective.

We have currently used 40 line FRC, to cover the current need of 31 lines and any additional requirements that may crop up. Pin configuration of FRC are shown in *Figure2*.

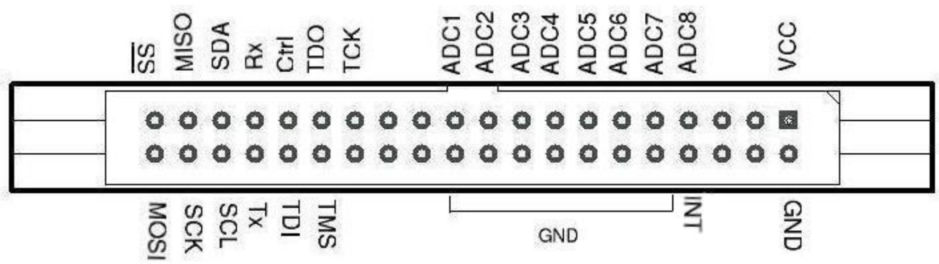

Fig. 2. Pin Configuartions on FRC

4 Testing

As a proof of concept or prototype, we have tried to build nodes with capability to monitor microclimate and seismic waves. Our initial goal is to build a functional node and not necessarily an optimized one.

To cover these two applications, our sensor board consists of light, temperature, humidity and pressure sensor as well as an accelerometer. These have a mix of analog and digital sensors. For testing purpose, We have built 5 nodes. Each node is having the same configuration and we have currently used easily available components to speed up the fabrication.

Processing Module: We have used Atmel ATmega32[7] microcontroller, which has 32 KB flash memory, 2 KB SRAM, 1 KB EEPROM. It also has 8 10-bit ADC, 32 programmable digital I/O lines as well as support for I^2C, SPI and USART. It can be easily programmed using the computer as well as self programmed. It does the function of collecting and processing the data from the sensor and transmitting the same to communication module, when needed. It also looks after the synchronization needs of the communication module as well as networking needs of the system.

Communication Module: Our present communication module consists of a pair of 433.33 Mhz transmitter and receiver. The receiver is always on i.e always

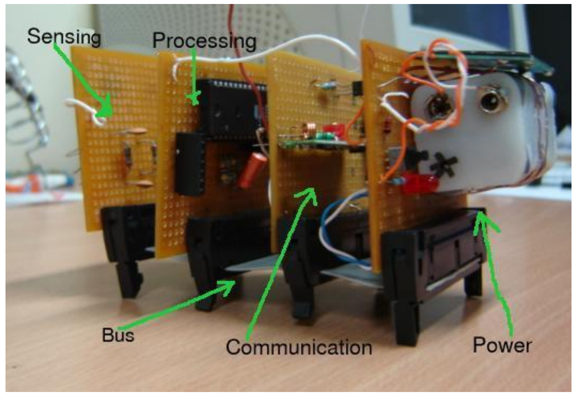

Fig. 3. A node of CENSE

listening, where as the power in the transmitter is controlled by the processing module, which switches it on only when transmitting data. The transmitter /receiver pair

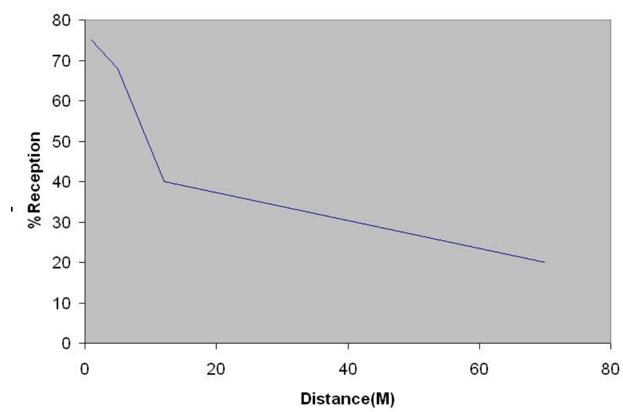

Fig. 4. Success rate of Transmission

was procured from Futuretechniks corporation[8]. Before integrating it with the full system, we tested the module using Stop and Wait protocol with two nodes. The graph in *Figure 4* shows the success rate of transmission between the nodes when the distance between them is varied. The transmission success rate drops rapidly beyond a distance of 5 meters. We are trying to understand the reason for this and extend the range (Individually transmitter/receiver pair has a much longer range).

Power Module: This module contains 4 AAA rechargeable Ni-Cd batteries for powering the node and a 37x33 mm solar panel (SCC- 3733[9]) providing 6.7 V(Open Circuit) and 15 mA current for recharging the batteries.

Active Sensor	**Radio**	**Power(mW)**
Temperature	Tx	96.8
	Rx	92.25
Pressure	Tx	96.8
	Rx	92.25
Acceleration	Tx	57.8
	Rx	53.25
No Sensor	Tx	46.8
	Rx	42.25

Table 4. Power consumption of a Node with different Sensor and Radio configuration

Sensor Module: The board we have made contains light(LDR), acceleration (MMA6260[10]), temperature(Tmp175[11]) and a pressure sensor (MPX4115S[10]).

The initial testing has been done using only a single hop network. We have used a technique similar to "Push-to-Talk". There is a master node which queries all the other nodes and gets the sensor readings. The slaves are numbered. They are continuously listening to the RF communication. Whenever a slave gets a message containing its address, it captures the sensor data and sends it back to the master. This message also contains the slave's address.

A experiment was carried out in a closed space of a laboratory, involving only light sensors, as we could control the light intensity. Master node was connected to the computer and it was querying the slaves at a regular interval of time. The data it received was tranfered to the computer for storage and analysis. The variation in the light intensity was achieved by switching off/on the electric lights. It was seen that switching off the lights, resulted in a quick drop in the light intensity values coming from the nodes, which corresponded to the actual condition. This preliminary test was a success.

5 Ongoing Work and Future Plan

CENSE is an ongoing project. However we feel the discussion of this project with international research community can provide vital inputs to improve the final design and in turn serve the research needs better. We have prepared prototype of the testbed consisting of five nodes. After optimizing the design, a hundred such nodes would be prepared which can be deployed for field testing. On the processor module we are right now trying to implement multihop routing algorithms for messages generated by the nodes, so that a true sensor network setup can be achieved. We are developing a new communications module based on Zigbee protocol for wireless communication and are using CC2240 [12] chip for this purpose. We are also evaluating some other microcontrollers from TI[11] MSP series and ATMEL[7] AVR series for better performance. We are locating more optimal sensors for the initial applications with preference given to digital sensors. On the power module we are putting in more intelligence to get information about power consumption, residual charge and status of energy scavenging source. We are also working on developing a mobility platform.

6 Conclusion

We have presented protoype design and implementation of a modular testbed 'CENSE' for wireless sensor network. Each node of the testbed consists of four modules : Power, Processor, Sensor and Communication. System has been design to accommodate more modules, if needed. An interconnecting bus consisting of Power lines, Control lines, Analog and digital lines has been designed. For proof-of-concept testing, we have fabricated five nodes and have carried out preliminary integrated tests. The nodes are currently functional but we are improving our design based on the understanding achieved so far. Though a lot of work still remains in the regions of optimizing our design, we are confident that testbed would permit us to design well optimized system for a number of applications.

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