# Indigenous Mote Design for Wireless Patient Monitoring Station

Rajesh Kannan Megalingam, Vineeth Mohan, Ajay Mohanan, Paul Leons, Rizwin Shooja
Amrita Vishwa Vidyapeetham, Amritapuri, Clappana P.O, Kollam-690525, Kerala, India
rajeshm@am.amrita.edu, vineethmohan@ieee.org, ajay-m@ieee.org, paulleonsc@ieee.org, rizwin@ieee.org

***Abstract:*** **A WSN is a constellation of spatially dispersed independent sensors that can collaborate among themselves and a central monitoring station (CMS) to observe physical or environmental phenomena. A sensor node, also known as a mote, is a node in a WSN that can perform some processing, acquire sensory data and communicate with other nodes in the network. Each mote consists of a microcontroller, sensors, transceiver, external memory and a power source. In this application, a WSN is employed to supervise a patient monitoring system. Employing a wireless monitoring system will allow remote supervision, simultaneous supervision of multiple patients over a single server and better mobility and less clutter in the intensive care units (ICU). Since the monitoring system is wireless, the server can be kept out of the vicinity of the patient. This will free the fuddle caused by monitoring instruments in the ICUs. In this paper we propose to use a WSN mote with very basic functions. For instance, the sensor for monitoring pulse can be interfaced with a basic mote platform which will then be a part of the active wireless sensor network in the ICU with a unique mote ID enabling discrete monitoring over a remote server. Since the motes powered by in-built power units such as batteries, the monitoring system is unfazed by power failures in the ICU as the CMS will be kept elsewhere with sufficient power back-up. Motes are available only in developed nations which are very generic and have many unwanted functionalities which warrants for the very high cost when shipped to developing nations like India. We propose an indigenous design specifically crafted for medical applications that do away with all the unwanted functionalities and hence would be much more affordable and hence employable in economically confined applications**

## I. Introduction

With the flashing preferment in the field of automation and telecommunications we see more systems emerging with less manpower and more accuracy. One of the areas where accuracy and urgency plays a vital role is the medical field where precise observations are pivotal to the treatment of the patient. A Patient Monitoring System (PMS) allows the medical staff in a hospital to remotely supervise the status of its patients and alarm the staff in the case of an emergency. Using wireless sensor networks (WSN) to achieve the goal is a novel effort in redefining the way in which modern PMSs are perceived. Employing WSN not only allows remote supervision but is also power efficient with very low maintenance needs and it also cuts down the clutter due to various measuring instruments in the Intensive Care Unit (ICU). The system is economically much more feasible when compared to other such PMS commercially available in the market. A mote is the most basic element in a WSN. Here we propose an indigenous mote design with only the required on-board sensors that are needed for a PMS. The design does away with unnecessary modules which are available in commercially available generic motes. This further reduces the cost of the system.

## II. Motivation

Patients who are in Intensive Care Unit need continuous health monitoring. Using latest technologies we can check the health of the patients regularly. But usually these machines are imported from foreign countries and are very expensive when they arrive in developing countries like India. Hence only precocious hospitals can manage to get these chips and efficient patient care is lacking in India. In this paper we propose an indigenous low cost mote design which can monitor the patient’s health continuously using wireless technology. The patients need not be continuously wired to PMS for the vital parameter checks, which is very inconvenient for them [3], [4], [7]. Another advantage is that any vital parameter can be measured. The motes can be networked and hence an effective network can be created to allow the doctors to work remotely and can attend to patients in case of critical situations. As the cost of the proposed mote is lesser compared to the existing motes, it will play an important role in modernizing the health care units in developing nations and can save many lives.

## III. Related Work

An extensive research was carried out in the field of medicine and trying to integrate it with the burgeoning technologies in wireless communication. WSN motes are used for various range of applications including satellite communication [9], disaster management [8], home automation [11], traffic control

[10] etc. Most of the sensor nodes or motes that are currently available are not equipped with sensors that can measure parameters like blood pressure, heart pulse, and temperature of the patients. Researchers have contributed to stand alone motes which can measure only one vital parameter [12], [13].

In motes like Micaz and Mica2 of Crossbow and EZ430-RF2480 and EZ430-RF2500 Texas Instruments does not have onboard sensors. Sensors that are capable of measuring light, temperature, relative humidity, barometric pressure, acceleration/seismic activity, acoustics, magnetic fields and GPS position have to be plugged-in for those applications that tally. But Crossbow and Texas Instruments does not provide sensors for medical applications. Another company called moteiv manufactures motes like Tmote sky, Tmote Invent and Tmote Connect for different applications but none of them for medical purposes.

Intel‘s SHIMMER (Sensing Health with Intelligence, Modularity, Mobility, and Experimental Reusability) was designed as a wearable sensor and incorporates wireless ECG, EMG, GSR, Accelerometer, Gyro, PIR, Tilt and Vibration sensors. The main drawback of this product is that it is very expensive (EUR 199) and supplementary amount should be paid for the supporting software. This is not at all affordable for people residing in developing countries like India.

Taha Landolsi and A. R. Al-Ali [14] designed a wireless mobile logging device which measures a patient's blood glucose concentration, heart rate and pulse oximetry and converts the biophysical readings into numerical values that is displayed in graphical format in a PC. Normal readings are periodically reported to physician's monitoring system in the form of an SMS via the general packet radio service (GPRS) modem.

Many such research works were carried out for ambulatory patient monitoring. Our proposed paper highlights a new system to monitor patients in the Intensive Care Unit (ICU) and which is targeted exclusively for India-like scenario. The above mentioned research works and products are meant for people in developed countries and are tagged with exorbitant prices. Hence we devise a new indigenous system which is cost effective and at the same time meets the requirements.

## IV. Wireless Patient Monitoring Network

The Fig.1 shows the typical illustration of the indented application of the whole system. The Wireless Patient Monitoring Network (WPMN) aims at monitoring the critical parameters such as blood pressure, heart rate, temperature etc. of patients in an Intensive Care Unit (ICU) and report in the status of the patient dynamically to the concerned doctor and nearby nurse station. Sensors are attached to the patient's body and the measured biomedical signal is converted into numerical value using the ADC module which is suitable for wireless transmission using the indigenously designed mote. Each patient has an associated mote with a unique mote ID and with which the server maps to the corresponding patient's biomedical data in the server.

The mote transmits the data being monitored, on a regular basis, say, after every 5 seconds. Hence even if any emergency crisis arises, the server can warn the doctor and other staffs associated with that unit with an alarm or a personalized message to take necessary steps. A gateway is attached to the server in the nurse station which acts as router for properly identifying and storing the data of each and every patient without any confusion.

A gateway, similar to the router is attached with the server inside the nurse station. This maps and stores the biomedical data from each patient in an unique way in the server so that the data can be identified easily for a particular patient at any time.

## V. System Architecture

Architecture of the proposed mote consists of a microcontroller MSP430F2013, a Zigbee transceiver CC2420, a power source, voltage regulator, an external memory. For customized purpose we have a temperature and pressure sensor attached to the mote. This can be extended to pulse rate monitor and ECG measurement. Fig.2 shows the block level diagram of the proposed mote. The microcontroller used is Texas Instrument (TI)'s MSP430F2013 which has 16 bit RISC architecture. It also has 16-Bit Sigma-Delta ADC Converter. Highly precise 16 bit ADC is needed for better accuracy of the readings. Another advantage of using this microcontroller is that it has Ultralow Power Consumption and ultrafast wake up from standby mode, thereby reducing the overall power consumption of the microcontroller used in the system.

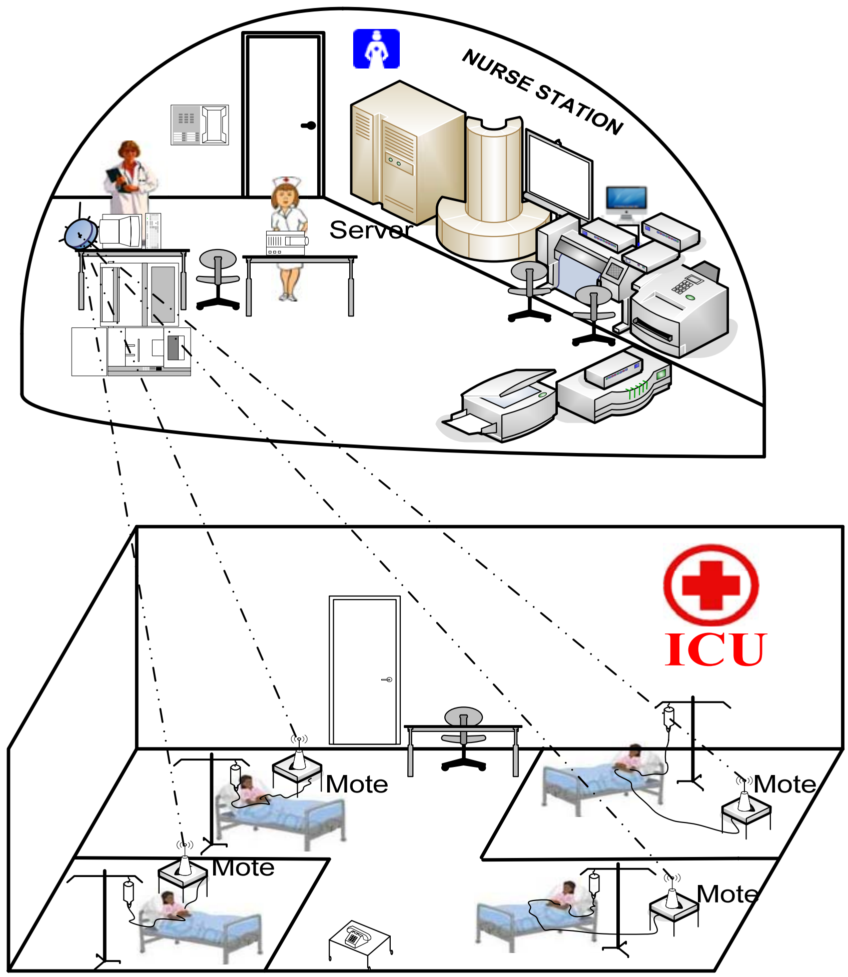


Fig.1. Illustration of Wireless Patient Monitoring Network

Next member in our architecture is CC2420 Zigbee transceiver which is also from TI. It is responsible for sending the processed information to the server using 2.4 GHz IEEE 802.15.4 Zigbee protocol. It's specially designed for low-power and low-voltage wireless applications. Another advantage of using this is its low cost. The configuration and transmit / receive FIFOs of CC2420 are accessed via Serial Peripheral Interface (SPI). It has 4 wire I/O pins for the SPI interface (SI, SO, SCLK and CSn). The SO pin is used as the data output of this IC whereas SI is an input for the IC. The CSn pin (Chip Select, active low) must be kept low during this transfer. SCLK is the serial clock that's transmitted to the IC.

For the temperature sensor application, we use MAX6635 from Maxim. It has a 12 bit inbuilt ADC which converts the analog readings into digital values and store them in a temperature register. The values in this register are readable by the microcontroller at any time through the I2C interface. This allows 0.0625°C resolution so that even a slight increase in patient's temperature can be detected using this system. This device is capable of reading temperatures up to +150°C. This is useful if the mote is used for other applications. MAX6635 feature a shut down mode that saves power by turning off everything except the power-on reset (POR) and the serial interface. It has an ALERT pin to alert the patient when the temperature has breached a specified limit. Using $I^2C$ interface, microcontroller can also be informed which further sends the signal to the server.

For blood pressure measurement we propose to use MPXV5050GP from Freescale semiconductors [15]. The MPXV5050GP piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor. It also has an inbuilt signal conditioner. So the output of sensor can be fed to ADC pins of MSP430F2013 microcontroller for digitalization. Output from sensor will have voltage range of 3.8 mV to 11.4 mV. So we use an amplifier to amplify this to 5.0 mV to 3.5 V using an op-amp. In order to maximize the resolution, this voltage range should be given as the reference voltage ADC.

There is no need for external memory as MSP430F2013 microcontroller has a 128B RAM. Since the data sampled are not stored in microcontroller for long time (most of the data are stored in server), internal memory would be more than enough. For the power supply MPXV5050GP need's voltage close to 5V. But other components need only voltages that are around 3V. So we have to provide 5V supply for MPXV5050GP and use regulator IC's output to other devices.

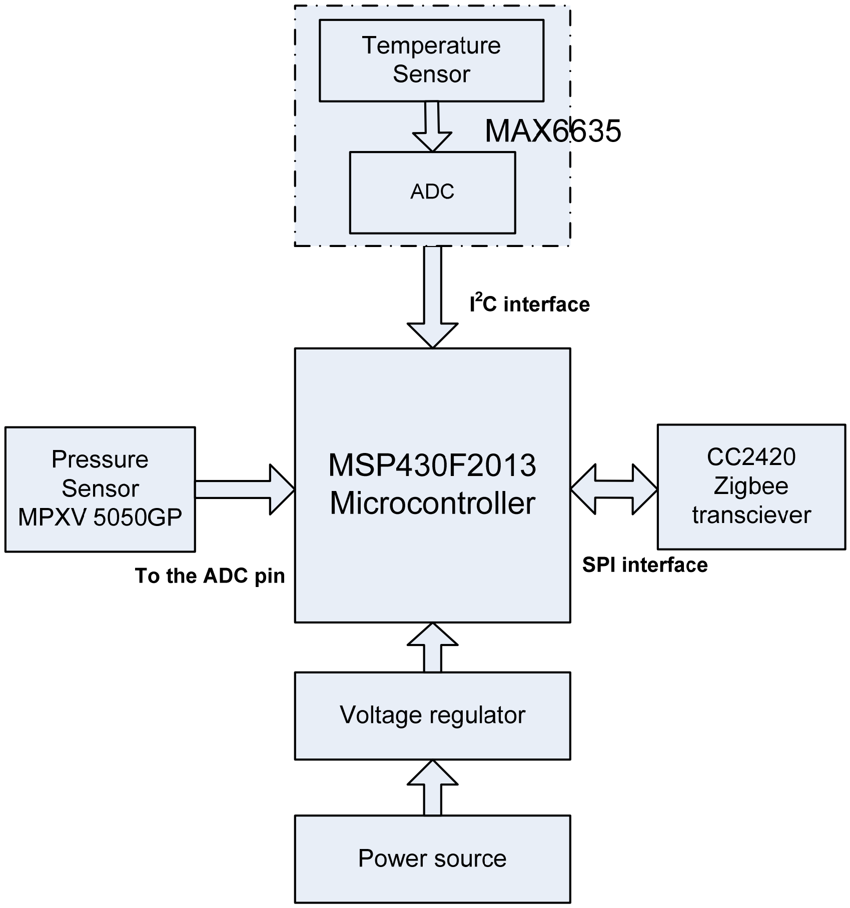


Fig.2. Block diagram of system architecture

## VI. Experimental analysis

In order to facilitate ourselves with sufficient knowledge and firsthand experience on working with motes, we bought a MPR2400CA mote (Micaz) from Crossbow Technologies and conducted a brief study on the various aspects like programming, interfacing with sensors, power consumption, hardware requirements, etc. Micaz motes from Crossbow are general purpose motes and have many features, all of which may not be needed for a specific application. In the case of a patient monitoring system, the application specific sensors are not available on-board and hence the idea of designing an application specific mote which do away with unwanted features and modules took shape. This will not only make it much more efficient in terms of performance, but also its economic viability will be increased manifolds.

The study included programming the MPR2400CA Micaz motes from crossbow technologies for different applications. The codes were written in nesC (*.nc files) language. NesC is an event driven programming language very similar to the popular C language, designed to embody the structuring concepts and execution model of TinyOS. TinyOS is an event-driven operating system designed for sensor network nodes that have very limited resources (e.g., 8K bytes of program memory, 512 bytes of RAM). The motes were programmed to perform send and receive operations (i.e. for data transmission over radio frequencies). Interrupt mechanisms were tested thoroughly and coding for initiating transmission upon receiving an interrupt were written in nesC. Xsniffer, a packet sniffing software, which comes bundled with Crossbow's Moteworks [9] OEM, was used to observe and track radio transmissions by the motes. Xsniffer enables the user to track the packets transferred and also extracts vital information like the mote id, transmission power, group id etc. MATLAB 7.30 was used to process the data obtained through Xsniffer [10].

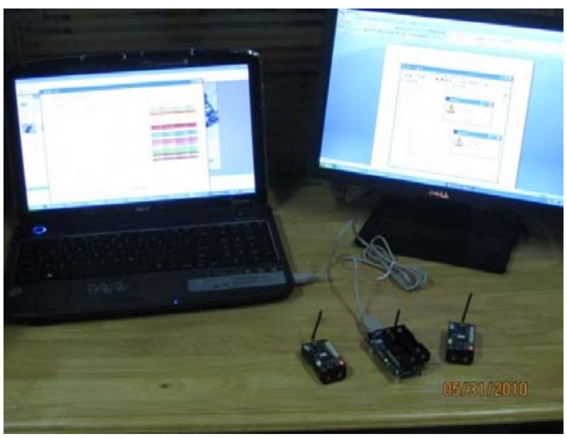


Fig.3. Experimental setup while analyzing commercially available motes

The study helped in gaining an in-depth knowledge about the various aspects of working with WSN motes like the internal architecture, hardware and software requirements etc. It also gave an overall view of the various limitations of the commercially available motes which have been sorted off in the proposed design. Fig. 4 shows the Xsniffer 'Option' Window used with the Crossbow motes for packet sniffing.

## VII. Cost Analysis

TABLE I
COST ANALYSIS

| Component | Cost (In Usd) |
|---|---|
| MSP430F2013 microcontroller | $1.0 |
| CC2420 Zigbee transceiver | $3.0 |
| MPXV5050 (pressure sensor) | $8.0 |
| MAX6635 (temperature sensor) | $3.0 |
| OTHER EXPENSES* | $ 10.0 |
| TOTAL | $ 25.0 |

TABLE II
COST PER NODE

| Mote Platform | Price | Comments |
|---|---|---|
| TelosB | US$99/$139 | no sensors/with sensors |
| Micaz/Mica2 | US$99 | Mica2 no longer available |
| SHIMMER | EUR199 | base SHIMMER SDK with 2 boards, several sensor boards and software available for EUR 1900. |
| IRIS | US$115 | |
| Sun SPOT | US$750 | 3 base boards and 2 sensor boards |
| EZ-RF2480 | US$99 | 3 nodes, one is a USB interface |
| EZ-RF2500 | US$99 | 2 nodes |
| Indigenous Mote | US$25 | Single Node with sensors |

The manufacturing cost estimated mote is estimated to be $25. So if we manufacture the motes in large scale, the cost can be even reduced. Crossbow's mote cost around $100 which has no onboard sensors either. Hence the economic feasibility of the proposed design is comparatively very high as it cost only 1/4th of the commercially available motes. Table 2 [1] compares various mote prices with/ without sensors with the proposed indigenous mote cost.

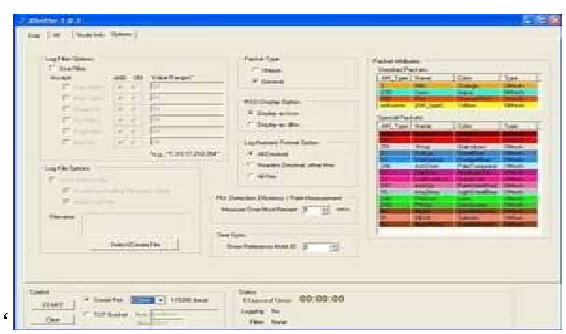

Fig.4. Xsniffer 'Option'Window motes

## VIII. Conclusion

A comprehensive and thorough analysis of implementing WSN in PMS has been presented. Two practical sensor applications of WSN (pressure and temperature sensing) in this context have been identified. The proposed system is highly flexible and adaptive to Indian conditions. It is comparatively more economical when compared to the conventional advanced techniques involved in modern PMS due to lower deployment and maintenance costs. The proposed PMS is capable of remote supervision with minimum manual intervention and higher efficiency. The design is highly economic compared to other motes that are available in the market. Hence it is best suited for health care in developing nations like India which cannot afford costly equipments. Large scale deployment of the same will ensure better health care management.

## Acknowledgement

We gratefully acknowledge the Almighty GOD who gave us strength and health to successfully complete this venture. The authors wish to thank Amrita Vishwa Vidyapeetham, particularly the WSN Centre and Amrita Research Laboratory for kindly support and guidance. We would also like to thank VLSI lab for access to their research facilities.

## References

[1] Johnson, Michael Healy, Pepijn van de Ven, Martin J. Hayes, John Nelson, Thomas Newe and Elfed Lewis, “A Comparative Review of Wireless Sensor Network Mote Technologies”, IEEE SENSORS 2009 Conference, 978-1-4244-5335-1/09/

[2] Kyung Jun Choi and Jong-In Song, “A Miniaturized Mote for Wireless Sensor Networks, 10th International Conference on Advanced Communication Technology, 2008, Volume 1, Pg 514-516

[3] Fulford-Jones, T.R.F.; Gu-Yeon Wei; Welsh, M.;, “A portable, low-power, wireless two-lead EKG system”, 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2004. IEMBS '04, Page(s): 2141 – 2144

[4] Baozhi Chen; Varkey, J.P.; Pompili, D.; Li, J.K.-J.; Marsic, “Patient vital signs monitoring using Wireless Body Area Networks”, 36th Annual Northeast Bioengineering Conference, Proceedings of the 2010, Pg: 1-2

[5] Lubrin, E.; Lawrence, E.; Navarro, K.F, “Wireless remote healthcare monitoring with Motes”, International Conference on Mobile Business, 2005, IEEE Conference Proceedings, Pg: 235-241

[6] Pardeep Kumar; Young-Dong Lee; Lee, HoonJae, “Secure health monitoring using medical wireless sensor networks”, Sixth International Conference on Networked Computing and Advanced Information Management (NCM), 2010, IEEE Conference Proceedings, Pg:491-494

[7] Sokullu, R.; Akkas, M.A.; Çetin, H.E, Wireless Patient Monitoring System, Fourth International Conference on Sensor Technologies and Applications (SENSORCOMM), 2010, IEEE Conference Proceedings, Pg: 179 – 184

[8] Dr. Maneesha V. Ramesh, “Real-time Wireless Sensor Network for Landslide Detection”, in Proceedings of The Third International Conference on Sensor Technologies and Applications, SENSORCOMM 2009, IEEE Digital Library, 2009

[9] Lappas, V.; Prassinos, G.; Baker, A.; Magnuss, R., “Wireless Sensor Motes for Small Satellite Applications”, IEEE Antennas and Propagation Magazine, Volume 48, Issue 5, Pg: 175-179

[10] Rajesh Kannan Megalingam, Vineeth Mohan, Ajay Mohanan, Paul Leons, Rizwin Shooja, “Wireless Sensor Network for Vehicle Speed Monitoring and Traffic Routing System”, International Conference on Mechanical and Electrical Technology (ICMET 2010), IEEE Press Conference Proceedings (in print)

[11] Yang Li; Ji Maorong; Gao Zhenru; Zhang Weiping; Guo Tao, “Design of Home Automation System Based on ZigBee Wireless Sensor Network”, International Conference on Information Science and Engineering (ICISE), 2009, IEEE Conference Proceedings Pg: 2610-2613

[12] Taylor, S.A.; Sharif, H, “Wearable Patient Monitoring Application (ECG) using Wireless Sensor Networks”, 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2006, , IEEE Conference Proceedings Pg: 5977-5980

[13] Thaddeus R. F. Fulford-Jones, Gu-Yeon Wei, Matt Welsh, “A Portable, Low-Power, Wireless Two-Lead EKG System, 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2006, , IEEE Conference Proceedings Pg: 2141-2144

[14] Mohammed El Korek; Rawan Aloul; Taha Landolsi; A.R. Al-Ali; Yousef Al-Assaf, “Portable Integrated Multi-Signal Patient Monitoring System”, Innovations in Information Technology, 2006 , IEEE Conference Proceedings Pg: 1-5

[15] S. Chua and Siew Mun Hin, “Digital Blood Pressure Meter”, Sensor Application Engineering, Freescale Semicondcutor, Singapore.

[16] MoteWorks_Getting_Started_Guide_7430- 0102-01_B.pdf

[17] Xmesh User’s Manual, Revision D, April 2007, PN: 7430-0108-01,Crossbow Technologies, Inc.