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Design and Implementation of a Multi-Level Cluster Based Cognitive Radio Sensor Network

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ABSTRACT

The paper presents a hardware design for implementing a wireless sensor node with a feature of enabled cognitive radio. The cognitive radio enabled wireless sensor network (CR WSN) is actualized as an event driven network, where the sensor nodes are organized into two levels of cluster hierarchy. These clusters consist of its own cluster head which communicates the sensed data to the sink node over primary radio channels. From the present scenario, Federal Communication Committee (FCC) & Telecom Regulatory Authority of India (TRAI) had indicated the over utilization of unlicensed spectrum and the under utilization of licensed spectrum. To overcome the spectrum scarcity and to utilize licensed spectrum effectively, Cognitive Radios (CR) are proposed for randomized spectrum access in event-driven applications. A software implementation based on hybrid MAC protocol design is ensured for faster and reliable data delivery. This system is further integrated in an environment for the purpose of event-detection and monitoring.

***Index Terms*:** Cognitive radio, Cluster grouping, Medium Access Control and ISM bands.

I. INTRODUCTION

A sensor node is capable of sensing some physical phenomenon, processing the sensed data and communicating the observed measurements to the command center. These sensor nodes may also perform data aggregation/compression to reduce the communication overhead in the network. The WSN typically consists of a large number of low-cost sensor nodes that are deployed either randomly or manually according to the pre-determined configuration. Recently, wireless sensor networks (WSNs) have been used in wider range of applications, such as environmental surveillance, data collection, smart environments [1], earth sensing, and border protection [2]. The above mentioned features of WSNs have motivated the extension of WSN technologies to be used for unattended event-detection applications. The event-driven communication nature of WSNs typically generates a bursty type of traffic, which results in under-utilization of the reserved channels for the WSNs. The bursty type of traffic gives the response in an unpredictive manner so that the spectrum cannot be assigned on the basis of a timed sequence. Therefore, it is inefficient to allocate licensed spectrum band. On the other hand, it is not practical to use the unlicensed portion of frequency spectrum (ISM bands) as the recent reports by FCC have indicated that the unlicensed portion of the spectrum has become increasingly crowded while the licensed bands are vastly under-utilized. By effective spectrum allocation the system can be made more responsive to stimuli and maintain less wastage of spectrum.

This paper is organized as follows. Section 2 describes the spectrum scarcity problem in the present scenario. Section 3 describes the methodology of the system. Section 4 explains the hardware and software implementation. The experiment is carried out and explained in Section 5 and Section 6 follows the conclusion.

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II. SPECTRUM SCARCITY PROBLEM

To overcome the spectrum scarcity and to utilize licensed spectrum effectively, cognitive radios (CRs) have been proposed for allowing opportunistic spectrum access for unlicensed applications. A CR network (CRN) has unique characteristics that distinguish it from a traditional wireless network. It opportunistically utilizes the spectrum that are available and adapts its operating parameters (e.g., operating frequency, transmit power, etc.) according to the surrounding RF environment such that the performance [3][14] of the licensed primary radio (PR) users is protected. In this system, a CR enabled WSN system (CR WSN) is integrated to enable efficient and reliable WSN operation, in which some of the users in the network are allowed to opportunistically communicate over the idle PR channels.

This system propose a pre-deployed CR-WSN design which follows a two-level clustering [4] that is suitable for event detection and monitoring and is categorized as an event detection network, where the collected information alone is transmitted to the monitoring center (sink) when an event is discovered. The lower level of the proposed CR WSN consists of several clusters [5] of sensor nodes, each with its own cognitive enabled cluster head (CRCH). The upper level consists of a network of CRCHs. The data collected by a sensor node in a given cluster is sent to its CRCH over an ISM channel. The CRCH opportunistically transmits the real time sensed data over one of the available PR channels to the sink node. To achieve an efficient event-detection [6] CR WSN operation, customized hardware design and implementation, reliable sensing and data processing algorithms, and distributed medium access and coordination protocols are developed. This system can operate over licensed and unlicensed bands, and hence the problem of inefficient static spectrum allocation can be resolved. The major importance given in this proposed system is the faster and accurate data delivery on event occurrence.

III. METHODOLOGY

A WSN generally refers to a group of dedicated sensor nodes deployed randomly or manually for analyzing certain parameters. On an event-detection the data (alert) from the sensor node is send to the cluster head over an unlicensed ISM band (2.4 GHz). The cluster head on its data reception sends it over a free PR channel that is sensed by a spectrum sensing cognitive radio at the transmitter side. The data is send over a licensed band to the sink node. The system proposed here is an event-driven, so as a Carbon Monoxide monitoring system [7] is developed for this experiment.

The network model is mainly classified on two level clustering techniques: inter-cluster communications and intra-cluster communications which are explained in the later part of this section. A structural view of the pre-deployed GSM-enabled CR WSN is shown below.

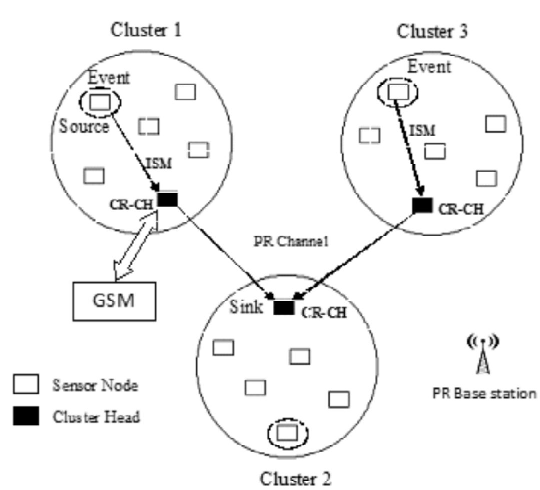

Figure 1: A pre-deployed GSM-enabled CR-WSN

1. *Intra-cluster communications*: The design employs an event-driven transmission strategy starting from the sensor node to its cluster head. The cluster heads receives real time up-to-date information about the detected events along with their locations. An ISM band with a frequency range of 2.4GHz transmits over the data to CHs. In each cluster, the sensor nodes adopt an extension of the CSMA/CA scheme used in the IEEE 802.11 standard with similar interframe spacings and collision avoidance strategies implemented over one of the ISM bands.

2. *Inter-cluster communications*: In inter-cluster communications, the cluster-head with received alarm packets forwards the packets to the sink over a PR channel. To facilitate multi-channel contention and channel assignment, the sink node maintains a free channel list (FCL) that represents idle PR channels within the monitored area. The FCL is continuously updated according to PRN activities.

IV. SYSTEM IMPLEMENTATION

The system describes a CR-WSN structure that uses a reliable MAC protocol [8] which addresses both intra-cluster as well as inter-cluster communications. In intra-cluster section a sensor node initiates the event on its occurrence. The sensor nodes are present within a cluster that senses the required data and communicates directly to the CRCH over an ISM band. As and when the event is detected, the CRCH transfers a message to the task manager with the help of a GSM unit attached along with the cluster head circuitry. In the inter-cluster section, cluster head adopts a cognitive multi-channel data transfer scheme that senses suitable licensed channel and data packets are further delivered to the sink node. With the use of licensed channel, the system experiences a faster delivery and better energy saving.

(A) Hardware implementation

The developed WSN system consists of mainly four types of nodes: a sensor node, a cluster head node, sink node and a GSM-enabled task-manager node. The cluster node and sink node has a powerful processing capability and is equipped with multiple transceivers. The system aims to eliminate various health problems that can cause due to excessive inhalation of pollutants in the air. According to the recent reports from International Pollution Control Board, the world presently faces Carbon Monoxide (CO) pollution in a higher rate. Here a carbon monoxide sensor is used at the source which senses the amount of CO and alerts the presence if in excess to the sink and to the task manager through a GSM unit.

The hardware design and implementation of the various nodes are as follows.

- **Sensor Node:** The sensor node circuitry includes mainly a CO sensor unit [9], a PIC microcontroller, a transceiver unit, voltage regulators and a power source. The figure 2 shows sensor node circuit design.

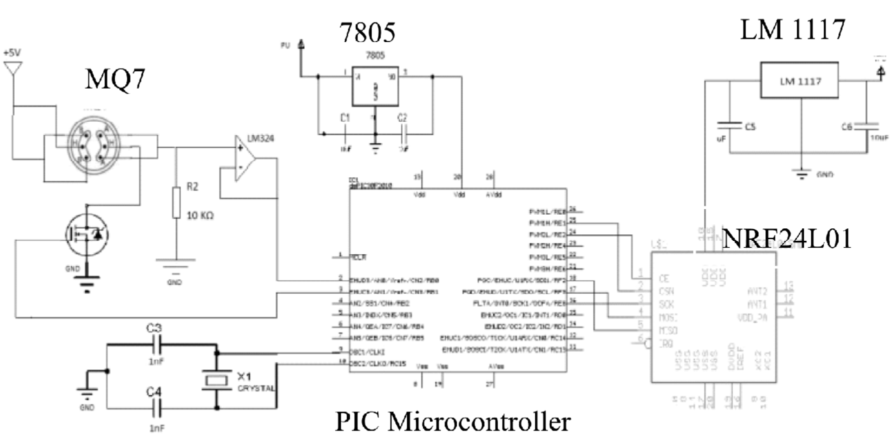

Figure 2: Sensor node circuit design

- **Task manager Node:** In this system task node is a GSM enabled mobile phone.
- **Cognitive Radio Cluster-head Node:** The circuit consists of the following elements: Cognitive enabled and half duplex transceivers, a PIC microcontroller [10], LCD Display, a GSM module, voltage regulators and a power source. Figure 3 shows the cognitive radio cluster head circuit design.

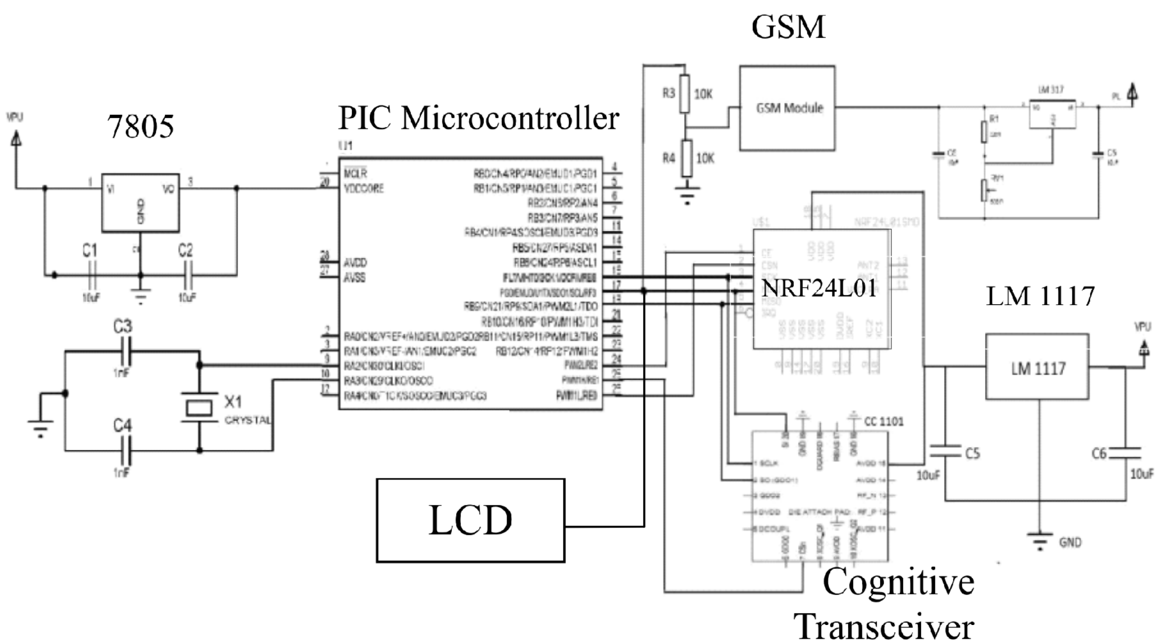

Figure 3: Cognitive radio cluster head circuit design

- **Sink Node:** The circuit comprises of the following elements: Cognitive enabled and half duplex transceivers [11], a display unit, a PIC microcontroller, GSM module, voltage regulators and a power source. The figure 4 represents sink node circuitry design.

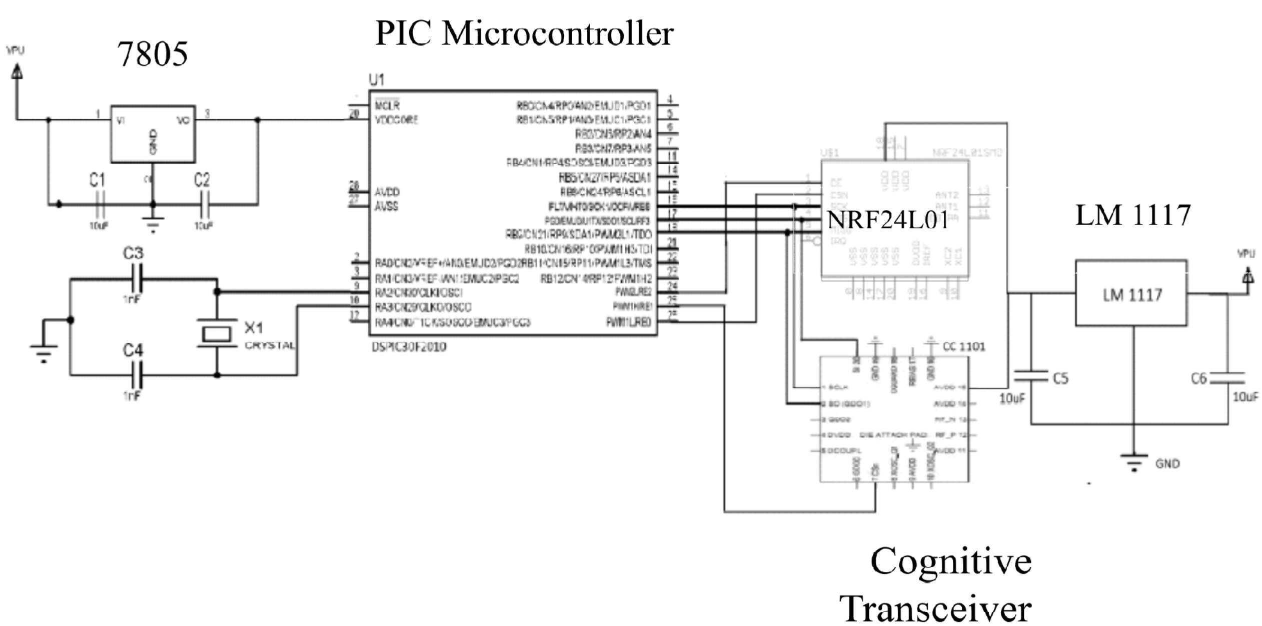

Figure 4: Sink node circuit design

(B) Software Implementation

A CR MAC design is implemented due to the clustering structure of the considered CR-WSN, called event-driven CR sensor MAC. The main objective of the cognitive radio is to obtain the best available spectrum through cognitive capability and reconfigurability property [12]. Multi-channel hidden terminal problem, sensing error, selection of common control channel, interference with primary users, sensing delay and network coordination problem might cause the MAC protocol to suffer from serious performance degradation. Selection of common control channel is one of the major problems under research in CR MAC. Common channel scheme is used to facilitate the continuous operation of the CR users without any disturbances. In this paper this dedicated channel is assumed to be owned by the secondary service provider. Thereby, complexity in primary user channel selection as Common channel control is abstained. The chance

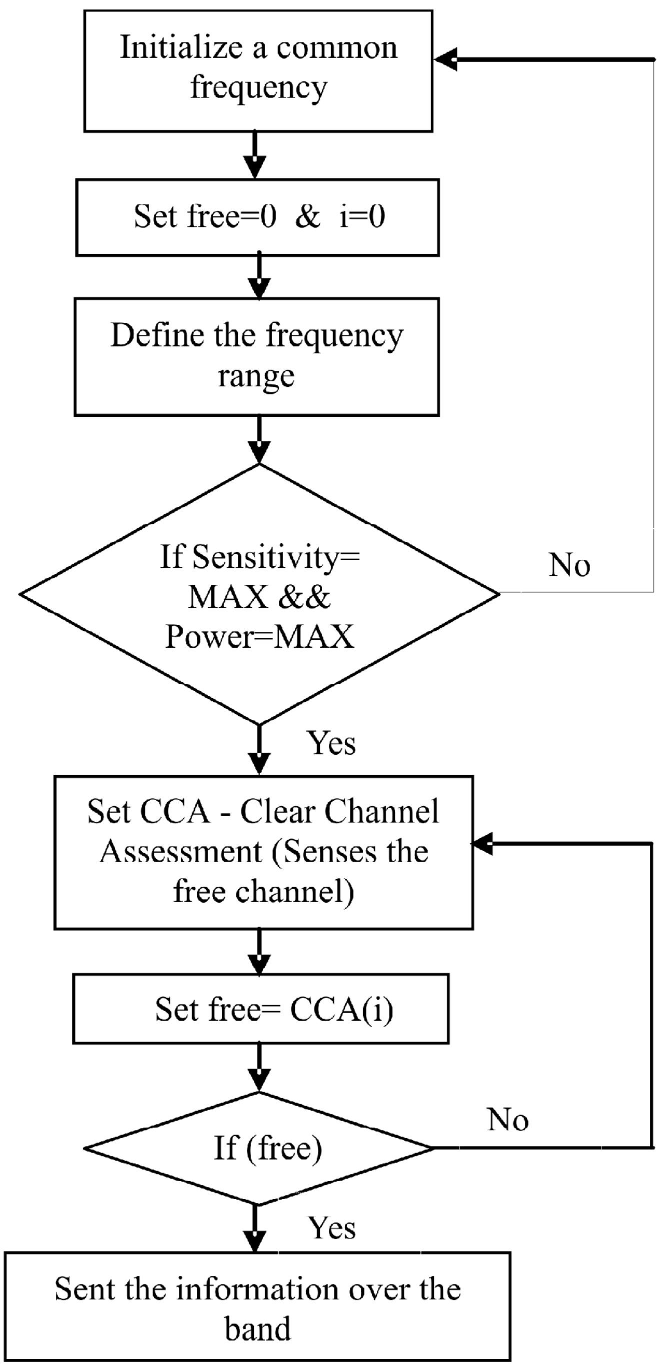

Figure 5: Flow diagram of transceiver transfer mechanism

of increasing system performance can be made desirable when SU senses many licensed channels within a smaller duration. A sensor equipped with main transceiver to sense multiple channels at a time thus reduce channel sensing time. The low sensing delay offers a better system throughput. In the MAC protocol efficient design of the contention phase can effectively address the MHTP. In addition the mentioned MAC protocol offers better coordination among SU’s and is less likely to collision with PU’s.

(C) Cognitive Radio Enabled Transceiver

These transceivers play an important role in this system for spectrum sensing [13], spectrum assignment and even transfer of the data. The build-in Clear Channel Assessment capability of the module enables it to extract the free spectrum around its range and assigns the free PR channels for the use. The feature of continuous spectrum analysis is facilitated so that if a spectrum gets to be busy, it automatically finds an alternate unused spectrum.

For the transceiver transfer mechanism using cognitive radio, a common frequency is initialized for generating new channel details. Further the frequency ranges that are available are defined. The cognitive enabled transceiver system searches for the free licensed band and once the channel gets set the information is send over the particular channel. The programming environment of the free sensing relies on the MplabX IDE. The embedded processing and IDE resource allows to build a better sensing system.

V. EXPERIMENTAL RESULTS

For the purpose of experiment, there was a need of an event-driven application. Considering the present rate in environmental pollution, a CO detection application was taken and considered for this purpose. In the first part of experiment the CO level is monitored in the cluster for 15 minutes. It shows the effectiveness, usability and its accuracy in communication of the designed sensor network. Here, MQ7 works as a CO sensor and serves the purpose of CO detection. Upon detecting an excess CO content by a sensor node, the sensor generates a fixed-size ($P = P_s + L$) data packets, where P_s denotes control information and L denotes the number of bits used to represent the CO concentration. On an experimental basis, mainly three clusters were considered that consists of two nodes and one CH. The intra cluster communication takes place between the sensed data at the sensor node and cluster head node. The communication is carried out over an ISM band that generally works with a frequency of 2.4GHz. The cognitive radio cluster- head node receives the data using an NRF receiver. The arrival of data is confirmed using an LED that glows on event detection and reception at the CH module. A specially designed cognitive module attached with the CH node senses the unoccupied licensed band and sends the data over it. Processes of spectrum sensing, data transmission and reception will be carried out in fractions of second. The cognitive module adapts a reconfigurability property which possesses customized transmission functionalities. The CH node is attached with a LCD that displays the frequency selected for transmission and the data transferred. The data is transferred over a licensed band so that users will be much less and these types of emergency event-detection applications could be carried out so easily. The frequency of selection is carried out in the cognitive radio module that uses a functionality called as Clear Channel Assessment. It possesses a property that indicates if the current channel is free or busy. These current CCA state is viewable on any of the pins by selecting particular modes. The use of GSM at the CH node helps to communicate with the supervisory end over the GSM bands. At the sink node the data is received via a cognitive radio transceiver. An LED is attached with the sink node circuitry that glows on the reception of data at the sink node.

(A) Table of comparison

The table 1 compares an existing system with a stable cluster structure [4] and the proposed grouping cluster structure that uses a cognitive radio with CCA functionality. The parameters put forward the effectiveness and accuracy of proposed system from the traditional system.

Table 1
Comparison between traditional stable cluster ss system and cognitive-enabled cluster system

Parameter	*Stable clustered system*	*Proposed cognitive - enabled cluster system*
Communication activity	Dedicated activity	Event-driven activity
Packet transfer rate	High	Higher than the traditional system
Band usage	Uses ISM band(2.4GHz)	Capable of using both ISM and PR channel bands
Protocol	MAC Protocol	MAC Protocol
Transfer Time	Time taken will be more as compared to proposed system	Less time data transfer as licensed band usage is involved
Accuracy	Lower as compared to the proposed system	Higher as compared to the traditional system
Stability	More prone to be unstable	Stable
System delay	Delayed when unlicensed bands are utilized	Delay gets low as licensed bands are presently under-utilized

VI. CONCLUSION

In this paper, an integrated hardware CR system (called CR-WSN) was proposed for event detection and monitoring applications. . The proposed CR WSN is a cluster hierarchy network with two levels of operations that are pre-deployed. The implemented system gives a faster response and transfer approach of data from the source to sink. The use of licensed spectrum helps in uninterrupted transfer of the data where the spectrum is selected effectively and efficiently using a cognitive radio module. A CR WSN test-bed with locally-designed and manufactured nodes was presented and tested through several experiments. Experiment results were positive and the performance of the system was reliable. The results showed a more reliable system for event detection and monitoring. A software implementation based on hybrid MAC protocol design was ensured for faster and reliable data delivery. Hence the system was further integrated in an environment for the purpose of event-detection and monitoring.

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