Development of SeatSense: A Wireless Sensor Network Based Seat Detection System

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***Abstract*—A task of locating particular seats in a partially (or otherwise) occupied auditorium can be difficult. The need for this may arise in a variety of situations in the emerging IoT-centric world. We present in this paper the development of a system we have tagged SeatSense. It is a means of detecting the availability or occupancy status of seats in any hall (of any conceivable capacity). SeatSense can find applicability in various indoor situations such as: concert halls, stadiums, churches, cinema halls and even outdoors e.g. in buses where seats are not pre-assigned. A sensor node located in each seat detects if it is occupied and feeds back information to a data sink where it is interpreted and visualized. This paper addresses the technical issues of designing and implementing seat occupancy detection technology in large auditorium with fixed or mobile seats using wireless sensor networks.**

***Index Terms*—IoT, IEEE 802.15.4, Sensors, WSN, Zigbee**

I. Introduction

Locating a particular seat in an appreciably large auditorium can be a daunting task, particularly when the hall is only partially full and people are standing. Knowledge of vacant seats will be of immense help to audiences who do not have designated seats, and for those who do, it would help to know the exact status of the pre-assigned seat (occupied/vacant). Knowledge of seat occupancy will also provide event organizers with data about present seat occupation and attendance patterns over time. Other applications of SeatSense include fraud detection in stadiums, health patterns (how long people are seated), trains, busses, churches and smart homes. The system discussed in this paper is a compact system consisting of: a seat occupancy sensor, microcontroller, networkable radio, and power supply. The entire system fits into an upholstered seat/chair. The design is cheaply implementable and energy efficient.
The rest of the paper is organized as follows. A system overview is presented in Section II. In Section III we discuss the system design and attendant technical nuances. We conclude in section IV and discuss recommended open research areas.

II. System Design

In the proposed system, each seat within the coverage area (arena, auditorium, etc) is equipped with one SeatSense unit and each unit is configured to be a node in a wireless sensor network (WSN). Information about present seat occupation is fed to a central base station, where seat occupancy readings from all seats within the coverage area are collated. Up to sixty seats connect to a base station in the proposed design.
Figure 1 illustrates the basic system architecture. The SeatSense nodes consist of the following components:

- Low-power microcontroller unit
- ISM band radio unit
- seat occupancy sensor
- CR2023 battery
- UART configuration port.

The SeatSense unit is designed to serve for a minimum of three years since they are embedded in seats and therefore are expected to be relatively inaccessible.

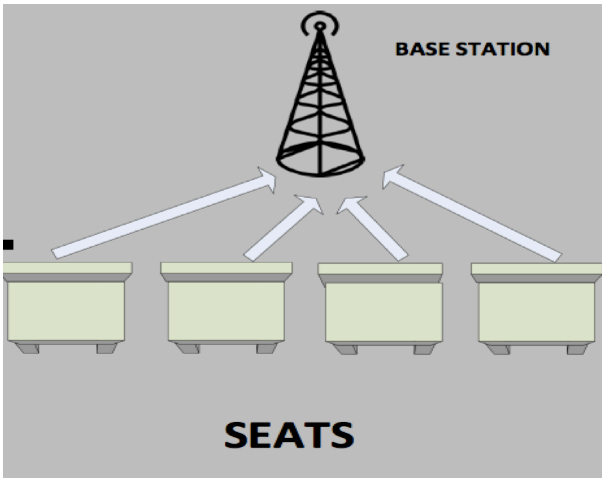

Fig 1. Connection of SeatSense nodes to Base Station

The microcontroller and radio module are in low-power sleep mode most of the time. A breakdown of the systems power consumption is done in the next section. The seat occupancy sensor used is a flexible force sensing resistor manufactured by IEE and originally intended for use in seat belt reminders in automobiles [1].
The resistance of the occupancy sensor varies with seat occupation status, dropping to less than 20Ω when the seat is occupied and in excess of 200MΩ when the seat is vacant. An I/O pin even in sleep mode powers the occupancy sensor. It wakes the microcontroller when the seat is occupied, during the seat occupancy period it is only powered ever 20 seconds and polled to determine if its ‘occupied’ status is still valid.

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The PIC16F1575 is a Microchip XLP (low power microcontroller) [2]. It is runs on its own internal 32 kHz oscillator most of the time, consuming < 20µA. However it switches to 500kHz oscillator frequency in packet transmission mode. The microcontroller configures and uses the radio module nRF2401+, powers and takes readings from the occupancy sensor. It interfaces to external configuration device using the universal asynchronous receiver/transmitter UART. In order to conserve battery life, the PIC16F1575 in predominantly in sleep mode, thereby consuming less than 50nA – despite powering the sensor module.

The radio module used is nRF2401+ 2.4GHz transceiver capable of up to 1Mbps [3]. In the SeatSense application it operates in ShockBurst mode in order to limit power consumption and avoid packet collision. It is interfaced to the microcontroller three-wire serial interface through which configuration and data are exchanged.

The nRF2401+ performs cyclic redundancy error checks (CRC) and address retrieval from received packets thereby simplifying software design. The RF module is in power down mode most of the time, coming on only to transmit data triggered by a change in the seat occupancy status. Portable configuration units are used to configure individual SeatSense nodes. Some parameters that can be set are: time interval of occupancy recheck, node unique ID, associating the node with a base station.

The configuration unit is linked to the node via UART. The nodal block diagram is as depicted in Figure 2.

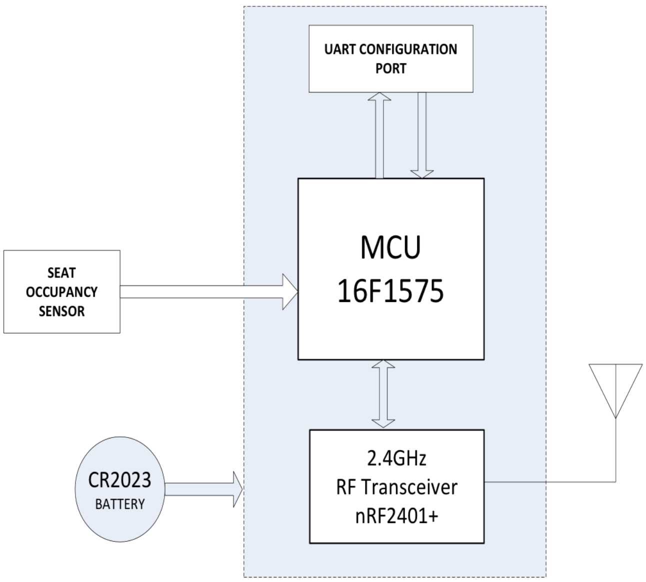

Fig 2. SeatSense node functional block diagram

III. System Description

A. SeatSense Network Architecture

The network architecture between seats and the cluster head is a star topology. SeatSense nodes are linked up into clusters not exceeding sixty seats, for ease of administration and technical considerations. Each cluster has a designated cluster head or base station, at which data is aggregated. These cluster heads are equipped with more powerful batteries and Zigbee nodes with ranges up to one mile in open air.

The Zigbee nodes form a mesh network over which aggregated cluster data is 'transceived'. Figure 3 illustrates clustered nodes formed into blocks; the cluster heads (depicted by a darker shade in the middle) are linked together.

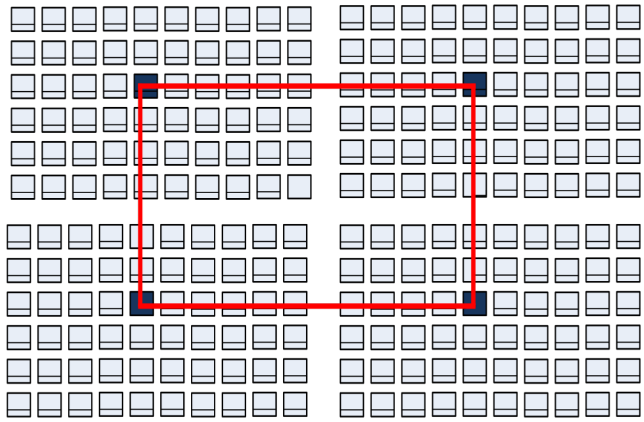

Fig 3. Networked Zigbee node cluster heads

In order to avoid packet collision, the nRF2401+ awaits a random amount of time ranging from 0 to 500ms before transmitting data about the seat vacancy. The purpose of this delay is to provide a primitive collision avoidance mechanism. This primitive MAC layer implementation allows the node to sleep for the length of the back-off period (in reception mode the nRF2401+ consumes 18mA current, in excess of the current consumed during transmission). Furthermore, the nRF2401+ is equipped with ShockBurst technology, which quickly transmits packets in order to avoid packet collision.

B. Network Modeling and Simulation

SeatSense nodes transmit a small packet to the cluster head when an event (seat occupation or vacation) occurs. The cluster heads forward packets and aggregate the collective data. The constituents of transmitted packets are illustrated in figure 4.

ADDRESS (16 bits)	PAYLOAD (16 bits)	CRC (8 bits)

Fig 4. SeatSense packet frame

The entire 40-bit packet takes at most 200µs to be transmitted at 250kbps while operating in ShockBurst mode according to the nRF2401+ device datasheet.

In order to select a maximum cluster size (operating on the same channel); we model the system as a block calls cleared system with only one channel, and since there are no acknowledgement messages, packet collision must be kept at the barest minimum. The packets arrive according to a Poisson distribution; there is a randomly varying delay that ranges from 0-500ms. We use the ErlangB blocked calls cleared formula to calculate the blocking probability depending on the number users transmitting on the channel.

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$$P_b = \frac{\frac{A^m}{m!}}{\sum_{i=0}^{m} \frac{A^i}{i!}} \quad (1)$$

P_b represents the blocking probability. A stands for the *Erlang*: a product of the call request rate and the holding time also referred to as offered load. While *m* stands for the number of channels in use (one channel is used per cluster in this work).
Cluster sizes of 300 nodes are used and figure 5. The blue line shows how the blocking probability varies as 80% of the 300 nodes in a cluster attempt to transmit packets. Meanwhile, the red line shows how the blocking probability varies when 20% of the nodes transmit at peak period

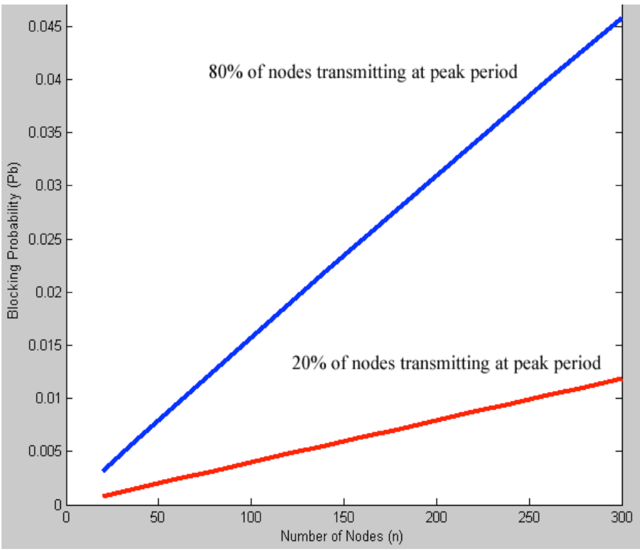

Fig 5. Blocking probability vs. Number of cluster nodes

It will be observed that the probability of packet collision increases drastically as the number of transmitting nodes in a single channel cluster increases and vice versa. Therefore, in locations where sensing events may occur simultaneously, such as in churches or stadiums, it is better to reduce cluster sizes or assign multiple cluster heads to a single node to increase probability of delivery.

A. SeatSense *Node Firmware*

Figure 5 shows the flow chart for seat occupancy detection. The seat occupancy sensor is powered via an I/O pin; this is feasible because it operates as an open circuit when the no one is on the chair. However, when a human sits, the resistance drops drastically; raising an interrupt which wakes the microcontroller from sleep; continuing to run current through the low resistance (< 20Ω) will take a heavy toll on the battery. Therefore, after the seat is occupied and the packet conveying this message is forwarded to the cluster head, the node returns to sleep waking up at set intervals (minimum of 20 seconds) to check the seat occupancy status. If it is detected that the seat is vacant, for more than 20 seconds, a packet is sent out indicating that the seat is unoccupied.
Operating the entire sensor network in mesh topology was considered for this system. However the drawbacks of this approach are the toll that packet forwarding takes on the battery life of intermediary nodes. Moreover, 802.15.4 (Zigbee) chips are more expensive. Zigbee is used for interfacing cluster heads since Zigbee can more easily be formed in multihop networks. Furthermore, Zigbee utilizes spread spectrum techniques, which are more immune to interference and signal fading [4].

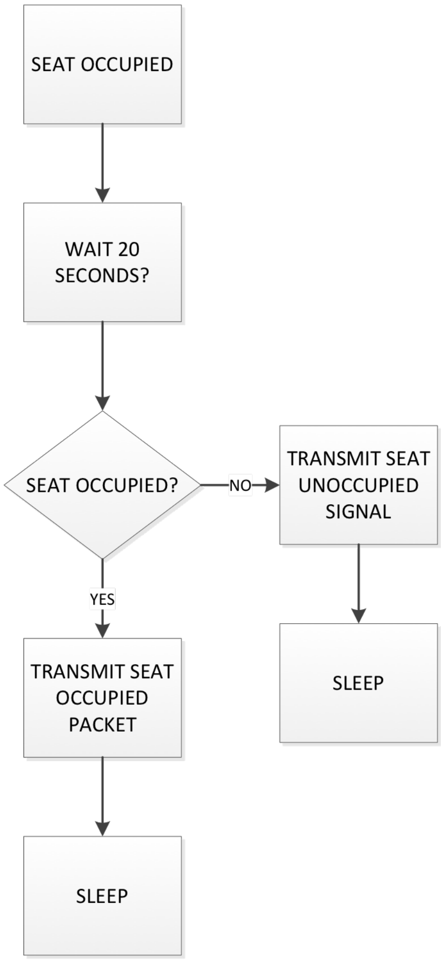

Fig 6. SeatSense occupancy verification flowchart

B. *Power Consumption*

Table I shows the current consumption pattern (CCP) of each of the main components in the *SeatSense* module.
The entire node is powered by a CR2023 lithium battery, which has a capacity 225mAh and operates at 3V. The system is designed to last through at least 100,000 sensing. However, intensity of use may affect long-term battery life.

TABLE I
CURRENT CONSUMPTION PATTERN (CCP) OF COMPONENTS

Component	CCP	
	Active	Sleep
MCU (32kHz operation)	<15µA	<100nA
MCU (500kHz operation)	<300µA	<100nA
nRF2401+ (ShockBurst mode)	<1mA	
Current through sensor	<300µA	

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IV. CONCLUSION AND OPEN RESEARCH AREAS

SeatSense sensor nodes is a cost-effective means of sensing seat occupancy with possible applications in auditoriums, stadiums, busses, trains, etc.

A possible application not explored in this work is in aircraft seats. However the effects of radio interference with aircraft equipment must be explored. WSNs are finding application in the aviation industry [5]. The cell size of 60 seats to a base station is arbitrary and probably suboptimal. Optimal cell sizes can be determined taking packet collision and interference into account is an open area of research. Alternative network configurations, interference, and improved security data security of the nodes are also open areas of research. A more sophisticated MAC protocol for the seat nodes is another open area of research [6]-[8]. We presented in another work [9], a novel trust-based fuzzy-inference algorithm (*FIGA*) for securing autonomous WSN interactions. Investigation into the application of this algorithm for the particular case of *SeatSense* will be an interesting study, particularly, in its capacity to prevent a malignant party from deducing lifestyle patterns and other private information from the *SeatSence* WSN.

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