Sensors & Transducers
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Wireless Sensor Network Based Smart Parking System

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Received: 21 September 2013 /Accepted: 22 November 2013 /Published: 31 January 2014

Abstract: Ambient Intelligence is a vision in which various devices come together and process information from multiple sources in order to exert control on the physical environment. In addition to computation and control, communication plays a crucial role in the overall functionality of such a system. Wireless Sensor Networks are one such class of networks, which meet these criteria. These networks consist of spatially distributed sensor motes which work in a co-operative manner to sense and control the environment. In this work, an implementation of an energy-efficient and cost-effective, wireless sensor networks based vehicle parking system for a multi-floor indoor parking facility has been introduced. The system monitors the availability of free parking slots and guides the vehicle to the nearest free slot. The amount of time the vehicle has been parked is monitored for billing purposes. The status of the motes (dead/alive) is also recorded. Information like slot allocated, directions to the slot and billing data is sent as a message to customer's mobile phones. This paper extends our previous work [1] with the development of a low cost sensor mote, about one tenth the cost of a commercially available mote, keeping in mind the price sensitive markets of the developing countries.

Keywords: Wireless sensor networks, Smart parking system, Sensor mote, Light-dependent sensors, Energy efficiency.

1. Introduction

Wireless sensor networks are ad-hoc in nature employing a large number of sensor motes communicating in a co-operative fashion with a Central Supervisory Station (CSS). The sensor mote being a battery operated device has limited computation and communication capabilities. Several environmental parameters can be monitored by interfacing the mote with different sensors. The wireless sensor networks have many advantages over its wired counterpart like flexibility, inherent intelligence, low cost, rapid deployment and more sensing points, especially in areas that cannot be wired. Owing to these advantages, the WSNs have found their way in diverse application domains such as facility management like traffic and parking management, health care, environment monitoring, intelligent buildings, disaster relief applications etc.

According to the International Organization of Motor Vehicle Manufacturers (OICA), the number of cars produced in 2011 alone stands at 59.9 million [2]. Ward's research [3] states that, the number of vehicles in operation worldwide surpassed 1 billion in the year 2010. In 2012 alone it was estimated that around 60 million cars would be produced (that is

165,000 cars produced every day) [4]. In urban areas, one-third of cars have reached their destination and are circling around looking for a parking space, leading to problems like pollution and traffic congestion [5]. With the explosive growth in automobiles, on-street parking will soon disappear, given the constraints on road space. Looking at the statistics provided so far we can conclude that better intelligent parking management systems like the one we are proposing will be required to handle the volume of cars/vehicles.

A number of WSN systems have been developed to address the car parking management. Typical car parking management systems monitor the number of cars passing the entry and exit points for estimating the free slots available. This result is then displayed at strategic locations for assisting the user. In [6], the system is developed using the DSYS25z [7], mote with magnetic sensors. The system described in [6] concentrates on issues such as connectivity, sensing and network performance. In [8, 9] and [10], WSN based car parking systems are proposed, where each of these papers explore the possibility of using different kinds of sensors. They also propose different routing mechanisms for transferring the data from the source to the sink. Most of the existing systems have discussed a scheme in which the data collected from multiple sensor motes is analyzed by a central station and is displayed at strategic points to assist the user. Majority of the solutions proposed also seem to be on the higher end of the pricing scale, and may not be a viable solution for price sensitive markets of developing countries.

In this paper, we propose and implement a car parking management system using wireless sensor networks in a cost-effective and energy efficient manner. Each mote is a battery operated device, equipped with only one passive ambient light sensor, to detect the presence or absence of a car. The sensor mote also conveys information like the amount of time the car has been parked and also the health status of its batteries. The radio module at the mote is allowed to "sleep" at regular intervals, thereby making the system energy efficient. The proposed system is completely automated and does not require the presence of a human at the entry or exit point. The system not only displays the availability status at strategic locations, but also sends the information such as slot allotted, time parked, billing information and directional details to the user's mobile phone via Short Message Service (SMS). According to International Telecommunication Union (ITU), there were 5.9 billion mobile subscribers in the world in November 2011 [11]. Generally, in order to associate a parking slot to a particular vehicle, a mote needs to be present on both the vehicle as well as at the parking slot. We propose a solution in which we reduce the number of motes by half by placing the mote only at the parking slots. We achieve this by using the free incoming SMS feature present in all mobile phones. The user is asked to enter his mobile number when he enters the parking facility. The number is then used to tag the user to the parking slot. This will reduce the number of motes by 50 %. Hence, we have opted to convey the parking information via SMS. Furthermore, including the SMS feature helps us avoid the usage of paper or plastic cards that are currently used for the purpose of parking/billing. Keeping in mind the cost involved in the deployment of WSNs, we present a custom-built, low-priced 8051 microcontroller based mote, which has been tailored to work efficiently to solve the problem of smart parking. The reduction in the system capabilities, like low computing power of the processor and use of a single sensor, has been compensated by the use of intelligent algorithms without compromising on the robustness of the system.

This paper is organized as follows: Section 2 describes the system architecture and its operation. Section 3 discusses about the implementation details of the system. Section 4 describes the experimental setup. Sections 5 and 6 present the future work and conclusion.

2. System Architecture

The block diagram of the system is shown in Fig. 1 and the CSS comprises of components as shown in Fig. 2. The system design follows a hierarchical architecture. Each of the sensor mote is placed in the parking slot. A set of such motes form a cluster and communicate with the cluster head. The cluster heads are identical to the motes in terms of hardware, but differ in functionality. These cluster heads relay the information to the CSS.

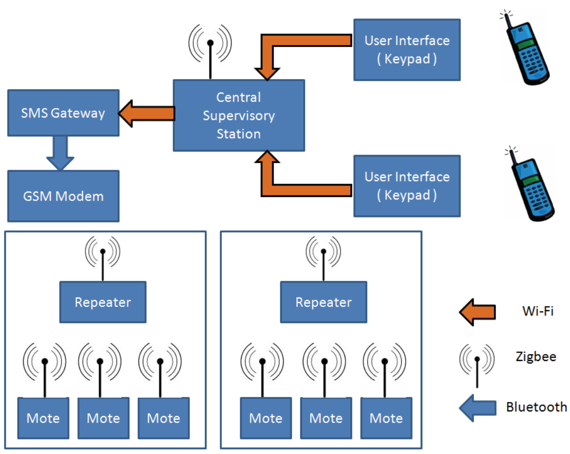

Fig. 1. System Architecture.

The operation of the system is as follows:

- When a user enters the parking facility, at the entrance, there will be a keypad and a display as shown is Fig. 3. The driver enters his mobile number using the keypad. This is done to associate the parking slot with the user.

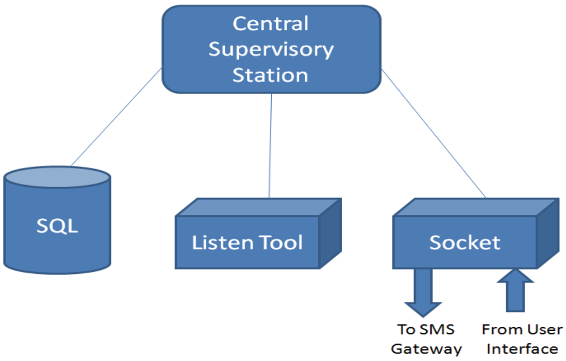

Fig. 2. Central Supervisory Station Components.

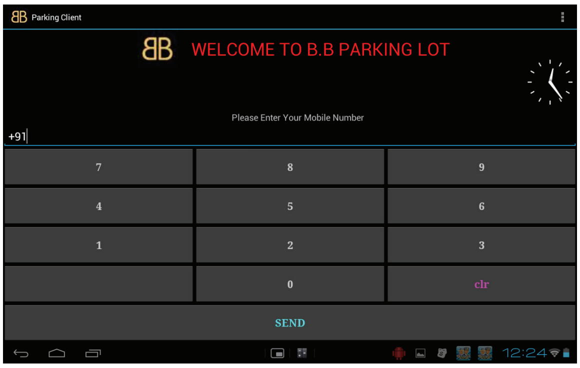

Fig. 3. End User UI.

- On successful entry of the mobile number, information regarding ID of the nearest empty parking slot, time of entry and route direction will be displayed on the monitor. The user will also receive these details via an SMS.
- The CSS is interfaced with a GSM modem to facilitate in sending the SMS. A java based SMS gateway at the CSS provides the essential functionality using AT commands to the send the SMS.
- When the vehicle is parked in the designated slot, an indication is sent to the CSS, which starts a timer for the corresponding slot.
- The database of the motes maintained at the CSS is updated with the occupancy information along with the corresponding user's mobile number. This will tie the parking slot with the vehicle.
- When the vehicle is removed from the parking slot, an indication is sent to the CSS which stops the timer for that slot. The value of the timer corresponds to the duration of time the vehicle was parked. This timer value is used for billing purposes.
- The CSS searches the database for the mote ID, present in the packet it received. The mobile number field corresponding to that mote ID is extracted, and an SMS is sent to the user. The SMS will contain information about how long the vehicle was parked and the billing amount.
- By the time the user reaches the exit of the parking facility, he/she would have received the SMS containing the billing information.
- The motes present in the parking slots also communicate periodically to the CSS. This helps in monitoring the battery status of the motes.

Each parking slot will be equipped with our custom-built 8051 microcontroller based mote prototype as shown in Fig. 4 fitted with ambient light sensor to detect the presence/absence of a vehicle. The mote keeps track of how long the vehicle has been parked and sends this timing information to the cluster head, which in turn sends it to the CSS. The IEEE 802.15.4 (Zigbee Protocol) [12] is the protocol used for communication between the motes. The billing information is calculated at the CSS, based on the data received from the motes. The mote also sends the availability status of the slot to the CSS which is displayed on a suitable GUI as shown in Fig. 5. The CSS also monitors the battery status of the mote.

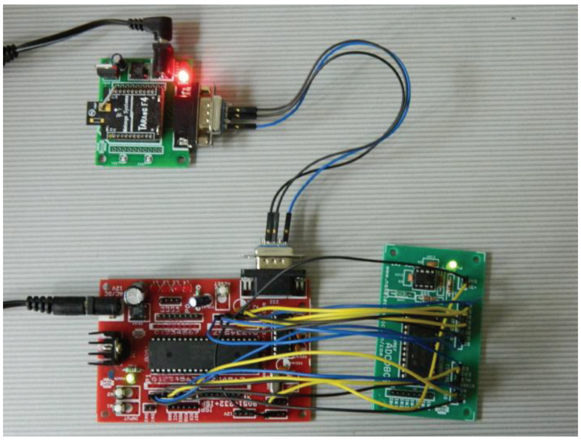

Fig. 4. 8051 Based Mote Prototype.

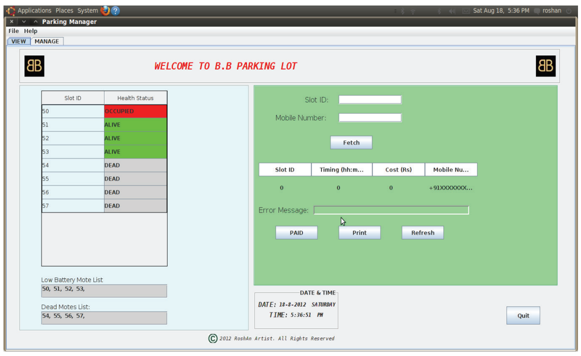

Fig. 5. Central Supervisory Station UI.

In the proposed system, a hierarchical scheme of communication is adopted. This will overcome the energy problems usually encountered in multi-hop routing strategy. A set of motes are grouped into a cluster. These motes then forward their data to the assigned cluster-head placed at a convenient distance from both the CSS as well as the individual motes in the parking area. The cluster-head simply retransmits the data it receives from the motes to the CSS. The cluster-head is identical to the motes placed at the parking slots in terms of hardware, but functions much more like the CSS. The CSS is a powerful processor capable of database support and interfaces with a GSM modem. The cluster-head and the CSS are powered from the AC mains.

3. Implementation Details

The flow charts of the system functionality at the CSS and at the sensor mote are shown in Fig. 6 and Fig. 7, respectively.

3.1. Occupancy Detection at the Parking Bay

To detect the presence/absence of a vehicle at a parking slot we employ the method of measuring the amount of ambient light using a light sensor. To ensure that light is incident only in the normal direction we place the sensor mote at the centre of the parking slot in a physical casing below the ground surface. The physical casing also ensures that the mote is protected from the physical damages. When a vehicle moves over the slot, the amount of ambient light reduces around the mote. Using this principle and by comparing the light intensity with a suitable threshold we come to a decision as to whether a vehicle is parked over the slot. An adaptive thresholding algorithm is used to set the light threshold based on the current light conditions.

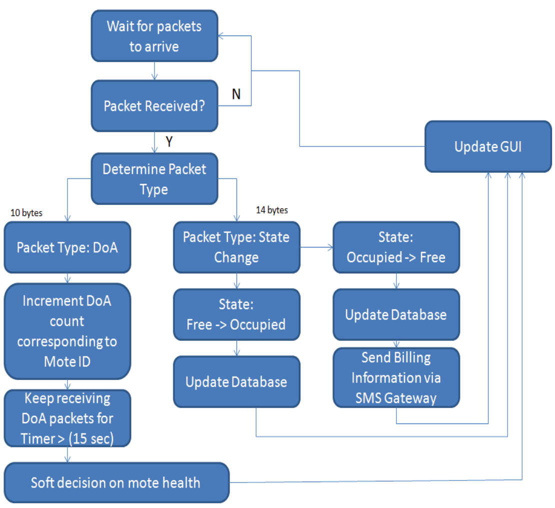

Fig. 6. Flow Diagram at CSS.

3.2. Adaptive Thresholding

In a parking bay the lighting conditions do not remain the same over a given period of time. We have introduced an adaptive thresholding algorithm such that the system adapts to the changing light conditions. The sensor monitors and records the light readings for a fixed interval of time. The recorded values are averaged and compared with the previous threshold. This makes the system intelligent and allows it to adapt itself to the varying lighting conditions around it.

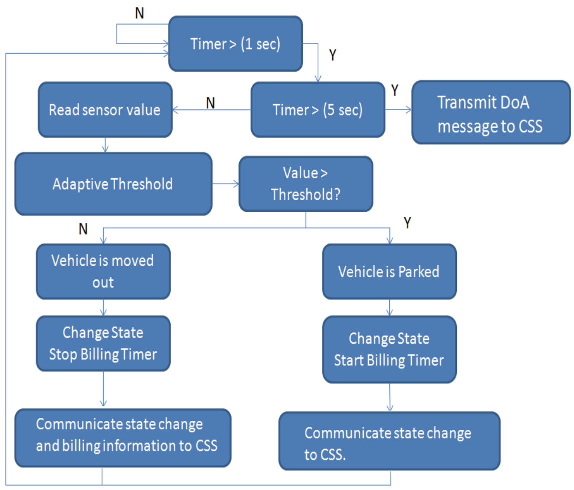

Fig. 7. Flow Diagram at Sensor Mote.

3.3. Packet Field Details

A 2 byte packet is transmitted each time information needs to be relayed to the CSS. The lower 8 bits of the packet are reserved for the device address. Bit 9 indicates the occupancy status; bit 10 indicates the battery level. Bits 12 and 11 together are used to indicate the type of message being transmitted. A “00” is a Dead or Alive (DoA) message, a “01” is a battery message and a “10” is an occupancy message. The remaining 4 bits are reserved for future use. The packet field format is as shown in Fig. 8. The packet generated is relayed to the CSS and at the CSS a java based sniffer is used to decode the packets. Once the packets are decoded a suitable decision is made based on the type of packet received.

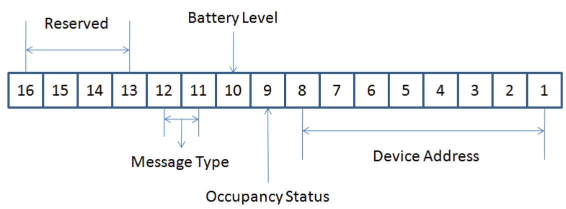

Fig. 8. Packet Field Format.

3.4. Battery Status

It is always useful to know the amount of operational life remaining on a device. We constantly monitor the battery value on the sensor mote. This is done by measuring the voltage potential of the battery and getting the same reading into the ADC unit of mote. Once the voltage potential of the battery reaches to 0.9 V [13] then a low battery status indication is transmitted to the CSS. The CSS updates the same in its database and displays a low battery status on the GUI.

3.5. DoA Beaconing

To enable the CSS to monitor the battery health status of the sensor mote and provide a graceful degradation to the system, we periodically transmit a DoA signal to the CSS. In our system we transmit this signal once every 5 seconds. The entries of all the motes are maintained in a database at the CSS. A soft decision, as to whether the mote is functional or not, is made by taking an average over three consecutive readings.

3.6. Optimization of Packet Transmission

Radio transmission on the sensor mote consumes the most amount of the battery energy. To reduce the excess consumption of the battery due to repeated transmissions of data packet, we transmit the occupancy message only when there is a state change. This state change occurs only when the vehicle either arrives or leaves the parking slot. Hence, by enabling the radio only when there is a state transition greatly reduces the power consumption. Once the DoA message is transmitted, the radio unit on the sensor mote is put to sleep. The mote will be again turned ON once every 5th second or when there is a state change or when a battery message needs to be transmitted.

4. Experimental Setup

The project made use of the Crossbow IRIS-XM210 mote with MDA100CB sensor board during the initial testing. The aim was to build a low cost low energy sensor mote which we achieved. The custom built sensor board constitutes a simple 8051 microcontroller, a Tarang [14] Zigbee radio module and a CdSe photocell which is used as the light sensor. A voltage divider forms the basic circuit to connect the light sensor to the 8051 microcontroller via the analog to digital converter. Additional details of the Crossbow mote and the 8051 prototype can be found in Table 1 and 2 respectively. The CSS mote is connected to the pc via USB cable for monitoring and display purposes. Fig. 5 shows the display running at the CSS.

We conducted various tests at varied locations to test the functions of the systems. To test the adaptive threshold algorithm we placed the sensor motes at an indoor parking facility in a mall. The deployment of the sensor mote for the experiment is as shown in Fig. 9 and Fig. 10 shows a closer view of the same. To protect the sensor from physical damage by the vehicle and the environment, the sensor mote can be placed in a protective casing, a few inches below the ground.

Table 1. Hardware Specifications.

Attribute	Details
On Chip Data Memory	128 bytes (8051)
On Chip Program Memory	4 K bytes (8051)
Program Memory Address Space	64 K bytes (8051)
Serial Communication	UART
Analog to Digital Convertor	ADC 0809
Frequency Band of Tarang	2400 MHz – 2484 MHz
Transmit Data Rate of Mote	250 kbps
Outdoor Range of Mote	>300 m
Indoor Range of Mote	>50 m
Current Drawn (Tarang)	50 mA (Rx mode), 45 mA (Tx mode)

Table 2. Software Specifications.

Device	Software/Operating System
8051 Microcontroller	Embedded C and Flash Magic
Base Station - PC with Intel processor	Ubuntu 10.04
	Listen tool, GUI using JDK 1.6
	SMS gateway using JDK 1.6
	Socket Programming using JDK 1.6
	MySQL Database

5. Future Work

The system can be extended to operate in outdoor environments by the use of additional sensors, which can validate the decision of the existing sensor. The use of additional sensors also helps in improving the reliability of the system. The system can be extended to incorporate the IMS network so that SIP enabled devices can also get the same service. Mobile apps can be employed to provide location based services which give a better user experience by providing real time information.

Fig. 9. Deployment.

Fig. 10. Deployment under car.

6. Conclusion

The project successfully demonstrated the possibility of using WSN for multi floor parking facility. The system developed is fully automated, highly energy efficient and cost effective as only one sensor is utilized. The utilization of only one light sensor with the adaptive threshold algorithm was reliable in detecting the presence/absence of the car. As the application does not demand any complex routing mechanisms, our system implements the broadcast technique to communicate to the CSS. This is both simple in implementation and power efficient as opposed to unicast transmission which has a higher power profile due to the additional overhead to the packets. Finally the system also proposed a novel approach of associating the slot, timing, direction and billing information with the user's mobile number via SMS.

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