International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:8, No:6, 2014

A Wireless Sensor Network Protocol for a Car Parking Space Monitoring System

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***Abstract*—**This paper presents a wireless sensor network protocol for a car parking monitoring system. A wireless sensor network for the purpose is composed of multiple sensor nodes, a sink node, a gateway, and a server. Each of the sensor nodes is equipped with a 3-axis AMR sensor and deployed in the center of a parking space. The sensor node reads its sensor values periodically and transmits the data to the sink node if the current and immediate past sensor values show a difference exceeding a threshold value. The operations of the sink and sensor nodes are described in detail along with flow diagrams. The protocol allows a low-duty cycle operation of the sensor nodes and a flexible adjustment of the threshold value used by the sensor nodes.

***Keywords*—**Car parking monitoring, sensor node, wireless sensor network, network protocol.

I. Introduction

WIRELESS sensor networks have recently gathered a significant amount of attention and extended application areas. Many cities in the world suffer from severe parking problems caused by an explosive increase in the number of automobiles. Wireless sensor networks have shown potential in intelligent parking management services that can provide various types of information on the status of parking spaces for alleviating parking difficulties in cities [1]–[7].

In the literature, several different strategies were employed to detect and collect information on vehicles. Chen and Chang utilized ultrasonic sensors for detecting the status of parking spaces and proposed a non-standard network protocol [1]. Lee et al. and Tang et al. used a combination of ultrasonic and magnetic sensors and a combination of light and acoustic sensors in [2] and [3], respectively. Zhang et al. presented a vehicle detection algorithm using a 3-axis AMR sensor and an adaptive sampling mechanism to reduce energy consumption [4]. Benson et al. and Barton et al. proposed wireless sensor networks adopting magnetic sensors and hardware platforms that run tiny OS [5], [6]. Yoo et al. proposed a wireless sensor network based parking guidance system in which magnetic sensors were used to detect the movement of vehicles [7]. Moon and Ha proposed a car parking space monitoring system based on wireless sensor networks in [8], where each sensor node is equipped with a 3-axis AMR sensor and deployed in the center of a parking space. Their approach was power efficient in that sensor nodes operate in a very low duty cycle mode and transmit measured sensor data only when the data show abrupt variations exceeding a threshold level.

The paper elaborates on the wireless sensor network protocol implemented in [8].The sensor network is composed of a sink node, a gateway, a server, and a plurality of sensor node. All of the sensor nodes are connected to the sink node wirelessly, forming a star topology. Although the direction of data flow is usually from the sensor nodes to the sink node, the sink node can send a command to one sensor node at a time in the form of an acknowledgement. As the number of sensor nodes increases, the chance of collisions also increases, which does not cause a serious problem. In the proposed protocol, the frequency of data transmission by a sensor node is extremely low since a sensor node transmits measured data only when significant changes in the measured values are detected. This approach results in a low duty cycle of the sensor node and in turn longer battery life of the sensor node.

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II. System Architecture

Fig. 1 shows the car parking space monitoring system composed of a server, a gateway, a sink node, and multiple sensor nodes. Each of the sensor nodes is equipped with a 3-axisAMR sensor and installed in the center of a parking space to detect the availability of the parking space. The sink node communicates wirelessly with the sensor nodes by forming a star-topology network and collects information from the sensor nodes. The sink node communicates with the gateway through a serial communication channel. The gateway relays information received from the sink node to the server. The server determines the availability of a parking space based upon the received information and provides the decision result for drivers.

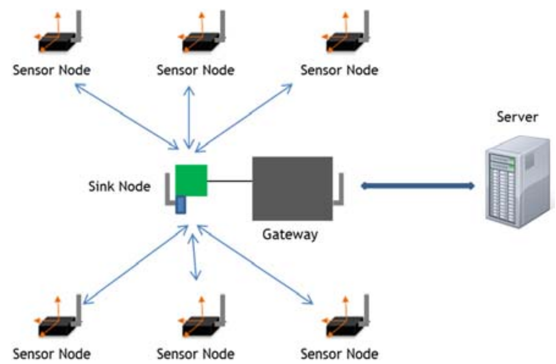

Fig. 1 Configuration of the car parking space monitoring system

Each parking space has a sensor node equipped with an AMR sensor deployed in the center. Fig. 2 and Table I show a picture of the sensor node with casing and the hardware specifications of the sensor node, respectively. Since motor vehicles create disturbances on the magnetic field of the earth, the AMR sensor outputs show significant differences when a parking spot is occupied and not. The change in the occupancy status of a parking spot, therefore, can be detected based upon changes in the output of the sensor mounted on the sensor node deployed in the parking spot.

Fig. 2 The sensor node in enclosure (lid not shown)

TABLE I
SPECIFICATIONS OF THE SENSOR NODE

MCU	ATMega128A
Sensor	HMC5883L
RF transceiver	CC1120
Frequency	447.9875 MHz
Data rate	4 kbps
Antenna	Coil antenna (0 dBi)
Battery	3.6 V Li-ion battery

The sensor node remains in a sleep mode during most of the operation time to conserve battery power and wakes up at predetermined time intervals to read the sensor data. Since the status of a parking spot does not change very frequently, the wake-up interval of the sensor node may be set to a few seconds. After joining the wireless network, the sensor node transmits the average values of sensor data measured while the associated parking space is not occupied to the sink node. As a result, the server has the initial average sensor values transmitted by each of the sensor nodes existing in the network and uses the values to determine the availability of parking spots.

III. NETWORK PROTOCOL

The basic role of the sink node is to relay the data from the sensor nodes to the gateway and to relay commands issued by the server to the sensor nodes. In the current implementation, there is only one server command to change the threshold value used by the sensor nodes. Because the sensor nodes may send data at any time and the sink node is powered by the server, the sink node does not enter a sleep mode and maintains its radio in the receive mode. Once a packet is received, the sink node acknowledges the data receipt to the sending sensor node and sends the received data to the gateway.

The data received from a sensor node contain the measured sensor values which show changes exceeding its threshold value and the used threshold value, thereby keeping the server informed of the current threshold value of the sensor node. The acknowledgement sent by the sink node contains a threshold value that the sensor node should use hereafter. The value might differ from the current threshold of the sensor node, in which case the sensor node replaces its threshold value with the new one. The threshold value included in the acknowledgement is sent to the sink node by the server. This is the mechanism by which the server can make the sensor node change its threshold value. If the server wants to change the threshold value of a sensor node, the server sends a new value to the sink node and then the sink node transmits the new value to the sensor node as an acknowledgement when the sensor node transmits a packet to the sink node.

Fig. 3 shows the flow diagram for the operation of the sink node. The sink node communicates with sensor nodes via the RF channel and the server via UART based on interrupts. After reset, the sink node executes an initialization routine and enables RF receive and UART receive interrupts. After that, its operation is interrupt driven. An RF receive interrupt is caused when a packet is received from a sensor node through the RF channel. An UART receive interrupt is caused when a new threshold is received from the server through the serial communication channel.

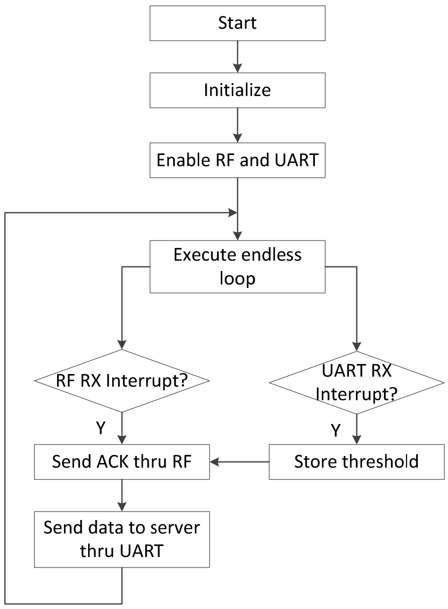

Fig. 3 The flow diagram for the operation of the sink node

If an RF receive interrupt occurs, the sink node sends an acknowledgement to the sending sensor node and sends the received data to the server through the serial communication channel. If an UART receive interrupt occurs, the sink node stores the data received from the server, which is a new threshold value of a sensor node, in its internal RAM. The new threshold will be sent to the target sensor node as an acknowledgement of the sink node when the sensor node transmits data to the sink node through the RF channel.

Since a new threshold value is sent to a sensor node as an acknowledgement of the sink node, the sink node cannot send the new threshold to the sensor node until the sensor node sends a packet to the sink node. Unless there are meaningful changes in the sensor values, the sensor node does not attempt an RF transmission to the sink node, which may lead to a very long time delay in the transmission of the threshold value. To prevent this problem, each of the sensor nodes transmits a data packet to the sink node periodically (e.g., at intervals of 30 minutes) without regard to the sensor values.

Fig. 4 shows the procedure for a sensor node to join the sensor network. After reset, the sensor node initializes its memory and peripherals and starts the RTC. The sensor node reads sensor values for a predetermined number of times for obtaining average data. The sensor node then checks if the RF channel is available for transmission. If available, it transmits the average data to the sink node and waits for an acknowledgement. If the reception of the data is acknowledged by the sink node, the procedure for joining the network is completed and the sensor nodes restart the RTC. The restart of the RTC is intended to reduce the probability of collisions with the other sensor nodes existing in the network. Unless an acknowledgement is received, the sensor node repeats the above procedure after a predetermined amount of time until the reception of data is acknowledged by the sink node.

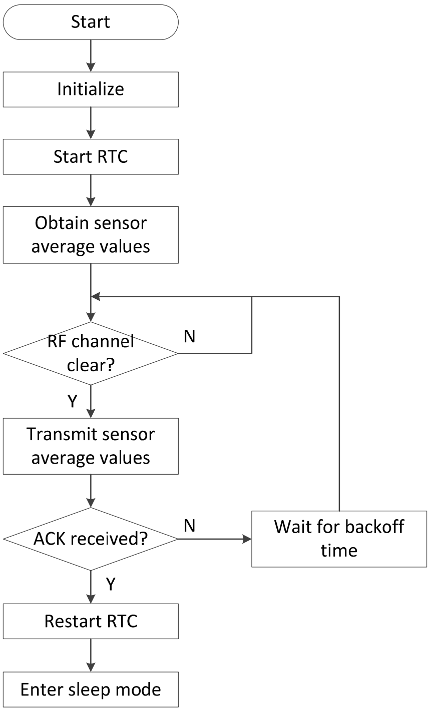

Fig. 4 The procedure for joining the network

Once a sensor node has joined the network, the sensor node enters a sleep mode and wakes up periodically at predetermined time intervals to read the AMR sensor data. Fig. 5 shows the operations executed by the sensor node after wake-up from the sleep mode.

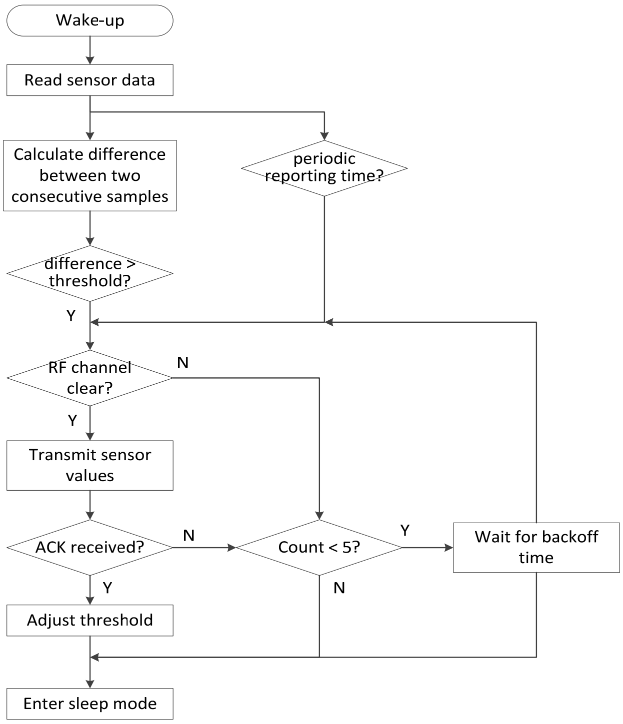

Fig. 5 Operations executed by the sensor node after wake-up

The sensor node reads sensor data and checks if the current and immediate past sensor values show a difference exceeding the threshold value stored in its nonvolatile memory. If the difference is greater than the threshold, the sensor node sends the measured sensor and the threshold values to the sink node by following a procedure similar to that for joining the network. In this case, however, the number of the repeated attempts for retransmission is limited to 5 for limiting power consumption. If the RF channel is not available after 5 repeated attempts, the sensor node enters the sleep mode.

The sensor node is supposed to receive an acknowledgement from the sink node after transmission of the data packet. If the acknowledgement is not received, the sensor node repeats the above procedure for a predetermined number of times. If it fails to receive an acknowledgement despite the repeated attempts, it enters the sleep mode. The acknowledgement received from the sink node contains a threshold value created by the server. The sensor node compares its current threshold value with the value contained in the acknowledgement. If the two values differ, the sensor node replaces its threshold value with the new value and uses the new value hereafter. Since the data transmitted by a sensor node also contain the threshold value used by the sensor node, the server always knows which sensor nodes have updated the threshold value and which sensor nodes have the old value.

If a sensor node communicates with the sink node only when the sensor values show significant changes, the communication may not occur for a long time. This makes it difficult for the sink node to assure that the sensor node works well and to make the sink node update its threshold value. To prevent this problem, the sensor node additionally transmits sensor data periodically without regard to the sensor values.

IV. Conclusions

A wireless sensor network protocol for a car parking space monitoring system was described in detail. In the proposed system, the number of RF transmissions by a sensor node is significantly reduced in that the sensor nodes simply transmit measured data only when the data show meaningful changes and regularly at a very low frequency. The regular transmission is required to notify the sink node that a sensor node is alive and to receive a new threshold value that may be transmitted by the server. The feature decreases the duty cycle and the power consumption of the sensor nodes, and therefore extends the battery life.

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