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A Car Parking Monitoring System Using a Line-Topology Wireless Sensor Network

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Abstract**—**This paper presents a car parking monitoring system using a wireless sensor network. The presented sensor network has a line-shaped topology and adopts a TDMA-based protocol for allowing multi-hop communications. Sensor nodes are deployed in the ground of an outdoor parking lot in such a way that a sensor node monitors a parking space. Each sensor node detects the availability of the associated parking space and transmits the detection result to a sink node via intermediate sensor nodes existing between the source sensor node and the sink node. We evaluate the feasibility of the presented sensor network and the TDMA-based communication protocol through experiments using 11 sensor nodes deployed in a real parking lot. The result shows that the presented car parking monitoring system is robust to changes in the communication environments and efficient for monitoring parking spaces of outdoor parking lots.

Keywords**—**Multi-hop communication, parking monitoring system, TDMA, wireless sensor network.

I. Introduction

THE increase in the number of vehicles has resulted in severe parking problems in many cities. Now that parking spaces cannot be increased unlimitedly, means for efficiently utilizing the limited resource are required. A way to alleviate the parking problems is to provide drivers with precise information on the available parking spaces of parking lots in real time. The demand for systems that can provide such information is expected to grow.

Nowadays, commercial buildings such as department stores and shopping malls tend to have indoor parking information systems for providing such information for their customers. Most indoor parking information systems use either ultrasonic sensors or cameras to detect parked vehicles. In the former case, ultrasonic sensors are usually attached to a structure installed above parking spaces and a sensor detects the availability of a parking space by measuring the distance to the object located below [1]–[3]. In the latter case, a camera detects the existence of vehicles by recognizing a particular mark [4]. The ultrasonic sensors and cameras are powered by a standard AC source and the detection result is transmitted to a server using wired communications.

Outdoor parking lots have different environments in several aspects and therefore cannot employ the car parking monitoring systems developed for indoor parking lots. Considering the fact that outdoor parking lots usually do not have structures on which sensors for detecting vehicles are mounted, we need to deploy the sensors in the ground. In addition, it is neither easy nor economical to construct a wired communication network for an outdoor parking lot. As a result, wireless networks are considered more efficient for outdoor car parking monitoring systems.

The car parking monitoring system proposed in [5] adopts a single-hop wireless sensor network with a star topology, where a plurality of sensor nodes for detecting the availability of parking spaces communicate with a sink node located at the center of the wireless network. In this system, all the sensor nodes communicate directly with the sink node using a CSMA (Carrier Sense Multiple Access) based protocol. Consequently, as the number of sensor nodes increases, the well-known hidden node problem is likely to occur more frequently. Besides, it entails the increase of the distance between sensor nodes and the sink node, which may give rise to communication quality problems.

This paper presents a car parking monitoring system for outdoor parking lots for solving the aforementioned problems of the previous system. The presented monitoring system adopts a wireless sensor network having a line topology and uses a TDMA-based multi-hop communication protocol called BiWSLP. The feasibility of the presented system is verified via experiments using 11 sensor nodes deployed in a real parking lot.

II. Previous Works

Fig. 1 shows the configuration of the sensor network used in the car parking monitoring system proposed in [1]. In this star-topology network, multiple sensor nodes communicate one to one with a sink node using a CSMA-based MAC. The sensor nodes are powered by batteries and remain in a sleep mode most of the time with a view to minimizing the power consumption. The sensor nodes wake up from the sleep mode at predefined intervals. After wake-up, the sensor node reads data of its sensor and transmits the measured value to the sink node. In consideration of the fact that the sensor nodes including the antennae are buried in the ground, the sensor nodes and the sink node perform communications in the 447 MHz frequency band that provides good diffraction properties and a long communication range.

Having installed and tested the star-topology sensor network in a real outdoor parking lot, we encountered two issues: the hidden node problem and low quality of the communication links between the sensor nodes and the sink node.

The sensor network uses a CSMA-based MAC protocol. If a sensor node needs to transmit data, it first checks whether the

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communication channel is idle and start data transmission only when the channel is sensed to be idle in order to avoid collisions. Since the sensors nodes are buried in the ground and powered by batteries, each sensor node is equipped with a small helical antenna and the transmission power is limited up to 10 dBm. On the other hand, the sink node, which is deployed on the ground and operates using an external power source, can be equipped with a higher-performance dipole antenna. As a result, the sink node has a wider communication range than the sensor nodes. All the sensor nodes are within the communication rage of the sink node but some sensor nodes are outside the communication ranges of other sensor nodes. In this condition, a sensor node may not detect that the sink node is busy communicating with another sensor node and may start transmission of data, which results in a conflict. The greater the number of the sensor nodes, the higher the probability of the hidden node problem.

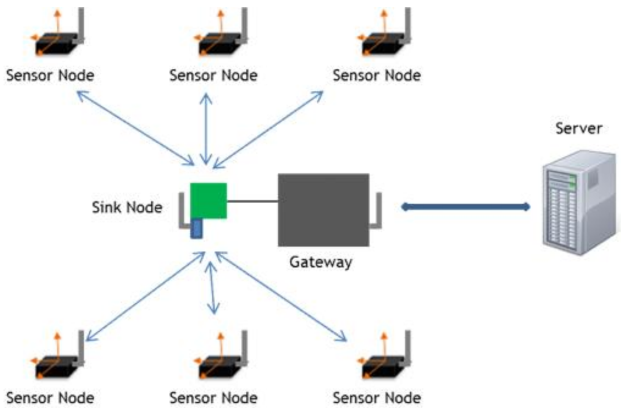

Fig. 1 The configuration of the sensor network adopted in the previous work [5]

Although the 447 MHz frequency band is considered to have a long communication range and good diffraction properties, it was observed that the communication links between the sink node and sensor nodes got broken in some cases. Fig. 2 shows two examples of such cases, where dark and white rectangles represent parked and free spaces, respectively. In the case of Fig. 2 (a), the communication between sensor node 1 and the sink node was reliable despite the vehicle parked over sensor node 1. On the other hand, when the parking space for sensor node 2 was occupied by another vehicle as shown in Fig. 2 (b), the link between sensor node 1 and the sink node got broken sometimes. This is because the car parked over sensor node 2 interfered with the communication between the sink node and sensor node 1. The distance between the sink node and sensor node 2 is approximately 25 m. Similarly, the communication link between the sink node and sensor node 1 remained good in the case of Fig. 2 (c), but the same problems were observed in the case of Fig. 2 (d).

This paper presents a car parking monitoring system using a TDMA-based sensor network with a view to resolving these issues. The proposed sensor network features a line topology and multi-hop communications. The data transmitted from a sensor node reach the sink node via several intermediate relaying nodes, in which case parked vehicles hardly interfere with the communications between sensor nodes since the distance between two neighboring sensor nodes is relatively short and therefore they can communicate through empty spaces under the parked vehicles.

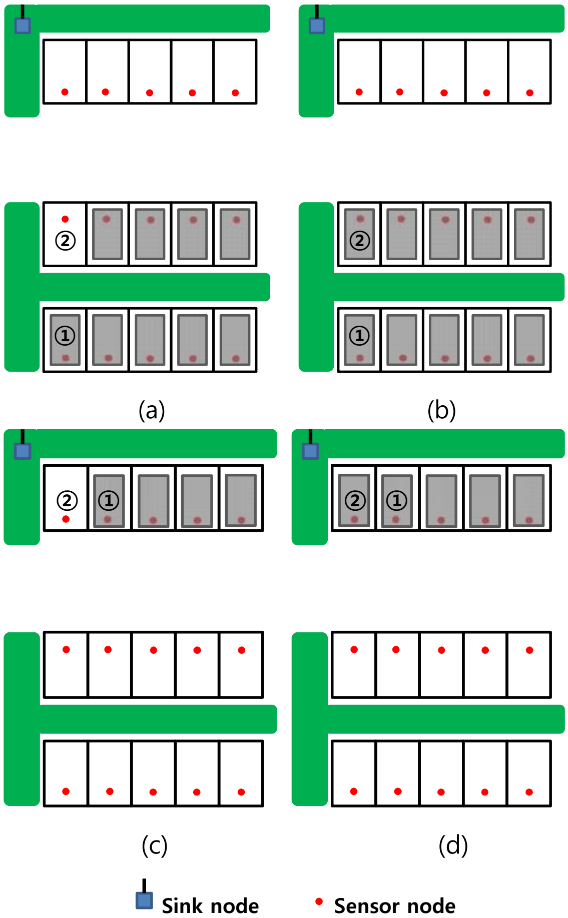

Fig. 2 Examples where unstable communications occur

III. Bidirectional Wireless Sensor Line Protocol (BiWSLP)

Bidirectional wireless sensor line protocol (BiWSLP) is a TDMA-based bidirectional communication protocol developed for sensor networks with a line topology [6]. In BiWSLP, each node is assigned a time slot during which it is allowed to communicate with neighboring nodes. A time slot is composed of three unit time slots, RX (receive), TX (transmit), and ACK (acknowledgement) in such a way that the TX slot of a node coincides in time with the RX slot of its upper node and with the ACK slot of its lower node, as shown in Fig. 3. As a result, the data transmitted from a node is received by its upper node and simultaneously received by its lower node as an acknowledgement. A node can verify whether its upper node has received the data that the node transmitted on its TX slot by monitoring its ACK slot.

In this manner, a virtual upward communication link is constructed from a terminal node to a sink node. The data transmitted from a sensor node reach the sink node through intermediate nodes, where a sensor node relay received data to its immediate upper node. In a similar way, a virtual downward communication link is also constructed from the sink node to the terminal node as shown in Fig. 3. The data transmitted from the sink node reach the terminal node through the intermediate nodes. While the upward link is usually used for collecting sensor data measured by sensor nodes, the downward link is used for transmitting commands issued by a server to the sensor nodes. The sum of the active and inactive durations is called the superframe period.

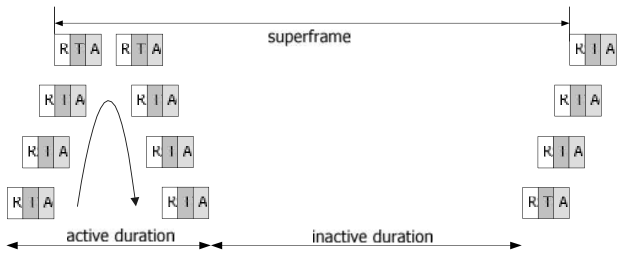

Fig. 3 The concept of BiWSLP

After transmitting/receiving data using the virtual upward and downward communication links, the sensor nodes enter a sleep mode for conserving power. After a predefined time interval, all the sensor nodes wake up from the sleep mode and repeat the data transmission and reception operations. The length of the active duration during which the sensor nodes operate is usually very short. The length of the inactive duration, i.e., the duration of the time in the sleep mode, varies depending on applications. In most cases, the inactive duration is much longer than the active duration, which allows a low power operation of the sensor network. For a more detailed description about BiWSLP, see [6].

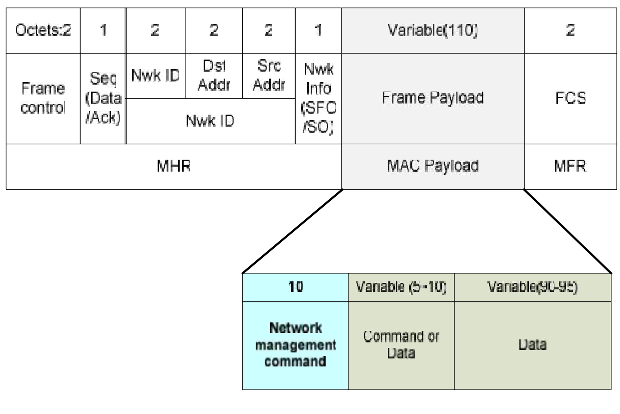

Fig. 4 The data packet format in BiWSLP

IV. A Car Parking Monitoring System Using BiWSLP

The environments for wireless communications in outdoor parking lots are diverse depending on the shapes of parking lots, parked vehicles, etc. It is therefore required that the sensor network work reliably in outdoor parking lots despite possible environmental variations. Since parked vehicles are obstacles to wireless communications, communication problems can arise when some parking spaces are occupied. Noting that there are still empty spaces under parked vehicles, the proposed sensor network is designed to perform communication through the empty spaces. Considering that parking spaces are placed side by side in most parking lots, the proposed sensor network adopts a line topology, where a sensor node communicates only with adjacent sensor nodes and the data from a sensor node are relayed to the sink node via intermediate sensor nodes.

One issue to consider is the frequency band to use. In South Korea, 400 MHz, 900 MHz, and 2.4 GHz frequency bands are allocated for unlicensed ISM (industrial, scientific, and medical) applications. Table I roughly compares the properties of the three different frequency bands. Because the sensor nodes are buried in the ground and should be able to communicate with other neighboring nodes even when vehicles are parked over the nodes, good diffraction properties are required. The maximum communication speed and the antenna size are also important factors to consider. The 447 MHz frequency band has the best diffraction properties but has the lowest bitrate. On the other hand, the 2.4 GHz frequency band has the highest bitrate but does not provide good communication links when the communications are interfered with by parked vehicles. In consideration of the advantages and disadvantages, we chose the 920 MHz band as the trade-off between communication quality and speed.

TABLE I
The Properties of Different Frequency Bands

	447 MHz	920 MHz	2.4 GHz
Diffraction property	very good	good	bad
Communication speed	1.2 kbps	50 kbps	250 kbps
Antenna size	large	medium	small

Another issue is the data bottleneck problem that may occur in BiWSLP. In the previous system [5] using a star-topology network, the communication between the sink node and sensor nodes are one to one; therefore, the size of data exchanged between a sensor node and the sink node are not critical. On the other hand, the proposed sensor network employs multi-hop communications. The parking space availability information of a sensor node is relayed to the sink node by its upper nodes, which implies that upper nodes tend to handle more data than lower nodes. As the number of sensor nodes increase, such a property may yield a serious data bottleneck, which may give rise to a significant delay in the data relay process. In this case, the size of data that a sensor node transmits needs to be reduced to lower the probability of the data bottleneck. To this end, each sensor node determines the availability of the corresponding parking space and only sends the availability status as a 2-bit value to the server, thereby reducing the size of the data to transmit. This is the main difference between the proposed approach and the previous approach [6] where each sensor node transmits the raw sensor data and the decision is made by the server.

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Fig. 4 shows the data packet format used in BiWSLP. A data packet is composed of a header of 10 bytes and a payload of 110 bytes. The payload is composed of a network management command of 10 bytes and remaining space of 100 bytes. The information on the status of a sensor node such as the battery level and ambient temperature is sent intermittently; it takes 5 ~ 10 bytes. As a result, the remaining space of 90 ~ 95 bytes can be used to deliver the information on the availability of parking spaces. Since the availability of a parking space is expressed as a 2-bit value, a data packet can deliver availability status of up to 380 parking spaces.

Fig. 5 The sensor node in enclosure

Fig. 6 The test environment

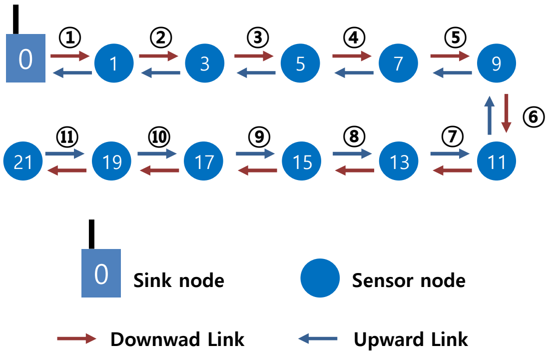

Fig. 7 The line topology of the formed sensor network

V. Experimental Results

We implemented BiWSLP on an 8-bit microcontroller. Tables II and III summarize the hardware specifications of the sensor node and timing parameters for BiWSLP, respectively. The superframe period of BiWSLP is set to 10 s and therefore the availability of each parking space collected at an interval of 10 s. Figs. 5 and 6 show the pictures of the sensor node and the parking lot where the sensor nodes are deployed, respectively. We constructed a wireless network by deploying 11 sensor nodes in the parking lot. 11 sensor nodes were deployed in 11 consecutive parking spaces shown in Fig. 6. A gateway connected to the sink node collects the information on the availability of parking spaces transmitted from the sensor nodes at the interval of the superframe period, i.e. 10 s. The gateway also collects the information on the network topology at regular intervals and transmits the collected information to a server. If a change in the network topology is detected, the gateway immediately transmits the new topology information to the server.

TABLE II
Specifications of the Sensor Node

MCU	ATMega2560
RF transceiver	CC1120
Frequency	920.1 MHz
Data rate	50 kbps
Antenna	Coil antenna (0 dBi)
Battery	3.6 V Li-ion battery

TABLE III
Timing Parameters for BiWSLP

RX slot	40.75 ms
TX slot	40.75 ms
ACK slot	40.75 ms
Superframe period	10 s

After being deployed, the 11 sensor nodes autonomously form a sensor network of a line topology, as shown in Fig. 7. In the case where a sensor node does not respond for some reasons after the network was constructed, the problematic sensor node is excluded from the network and a recovery process begins. Once the recovery process is completed, the sensor network has a different topology, which is immediately reported to the server. In other words, if the network topology remains unchanged, this implies that the communication links between sensor nodes are reliable and all the sensor nodes work well.

It is the main objective of the experiment to evaluate the reliability of the proposed wireless sensor network against variations in the communication environments. We tested the sensor network for 18 hours from 8 am to 12 am. The information on the network topology collected by the server for the test hours did not show a change in the network topology, which indicates that all the communication links between the nodes remained good despite the vehicles passing through or parked in the test area.

For quantitative evaluation of quality of the communication links, we tested the data receive rates of the sensor nodes. Now that the superframe period of the network is set to 10 s, each sensor node transmits and receives one data packet once at the downward link and once at the upward link at an interval of 10 s. All the sensor nodes were programmed to count the number of received packets for 10000 s and to transmit the number to the server every 10000 s. Fig. 8 shows the test result. The numbers from 1 through 11 denotes the link numbers. The bars on the left side and right side indicate the link quality expressed in % of the downward and upward links. It is shown that all the sensor nodes except for link 1 shows quality higher than 99 %. The result verifies that the communications between the sensor nodes remain reliable despite variations of the communication environments and the proposed line-topology sensor network is effective for monitoring outdoor parking lots.

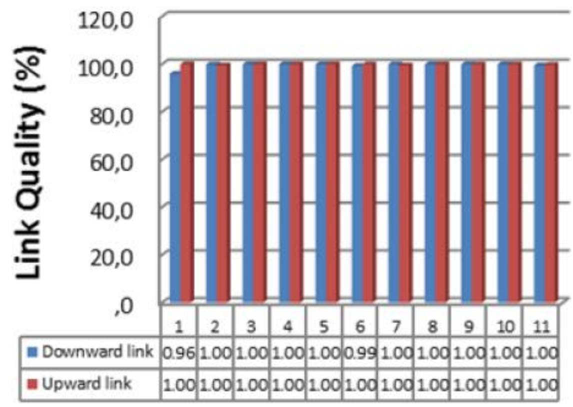

Fig. 8 The measured communication link quality

VI. Conclusions

This paper proposed a car parking monitoring system using a line-topology sensor network with a view to improving the reliability of the previous parking monitoring system using a CSMA-based sensor network. The proposed system uses a TDMA-based sensor network protocol called BiWSLP that supports multi-hop communications. We installed a sensor network using 11 sensor nodes in a real outdoor parking lot and conducted experiments to test the quality of the communication links between the sensor nodes. The result indicated that the proposed sensor network remained robust to variations of the communication environments and could be effectively utilized for monitoring parking spaces in outdoor car parking lots.

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