PGS: Parking Guidance System based on Wireless Sensor Network

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Abstract— **In this paper, we present PGS, a Parking Guidance System based on wireless sensor network(WSN) which guides a driver to an available parking lot. The system consists of a WSN-based VDS(vehicle detection sub-system) and a management sub-system. The WSN based VDS gathers information on the availability of each parking lot and the management sub-system processes the information and refines them and guides the driver to the available parking lot by controlling a VMS(Variable Messaging System). The paper describes the overall system architecture of PGS from the hardware platform to the application software in the view point of a WSN. We implemented the WSN based VDS of PGS and experimented on the system with several kinds of cars. The experimental results show that PGS succeeds in detecting various kinds of cars and the predicted battery life-time using measured current profiles is over 5 years.**

Keywords—WSN, VDS, Parking Guidance System

I. INTRODUCTION

In recent years, the desire to connect all electronic computing devices together and to embed computing devices in almost everything has increased. Although they can be connected through wired lines, it is more convenient and effective to use wireless links when we consider the large number of pervasive devices in the environment. Wireless sensor network(WSN) is one of the enabling technologies for such a ubiquitous computing world. Although WSN are still under development and research, it is expected that WSNs will be used in all sorts of applications including consumer electronics, PC peripherals, home automation, home security, personal healthcare, toys and games, industrial control and monitoring, asset and inventory tracking, and intelligent agriculture, typically[2][3]. In addition, cultural property management[10], ITS, and telematics also require the inclusion of WSNs. This is especially true in the telematics field where WSNs can be used to provide useful information such as road condition and traffic speed[11] and occupancy of a parking lot. Currently, these information are detected using loop detectors and sensors which are wired. Furthermore, they are very expensive and it is difficult to install and maintain them[1].

There are many researches dealing with the problem of vehicle detection with WSN[4~9]. However, there is a lack of real measurement and experimental data.

Here, we present the WSN based PGS system architecture which consists of the WSN based VDS(vehicle detection sub-system) and management sub-system. The VDS sub-system is used to detect the occupancy of a parking lot and report the result to the management sub-system. The management sub-system processes the gathered information and provides the information to the drivers. To evaluate the system, we implemented the WSN based VDS and experimented on the system with various kinds of cars. In addition, we estimated the battery-life time with simulation analysis based on the current profile measured with T-Sensor Node.

Our contributions are summarized as following. We present PGS system architecture based on WSN. We implemented WSN based VDS and evaluated the performance with several kinds of cars. In addition, we demonstrated the feasibility of battery-powered T-Sensor node with simulation analysis using real measured current profile.

The rest of this paper is organized as follows: Section 2 describes the system architecture of PGS and then Section 3 reports the experimental result and discussion for the result. Finally, the paper concludes with a summary of our work and a statement of future work in Section 4.

II. SYSTEM DESCRIPTION

In this section, we describe the PGS system including the WSN based Vehicle Detection Sub-system and management sub-system as shown in Fig. 1. The WSN-based VDS is designed to detect the occupancy of a parking lot and report the result to the management sub-system. The management sub-system consists of PIS(Parking Information Server) and a notice board such as a VMS(Variable Messaging System) and it gathers the parking availability information and guides the drivers through the VMS or PDA.

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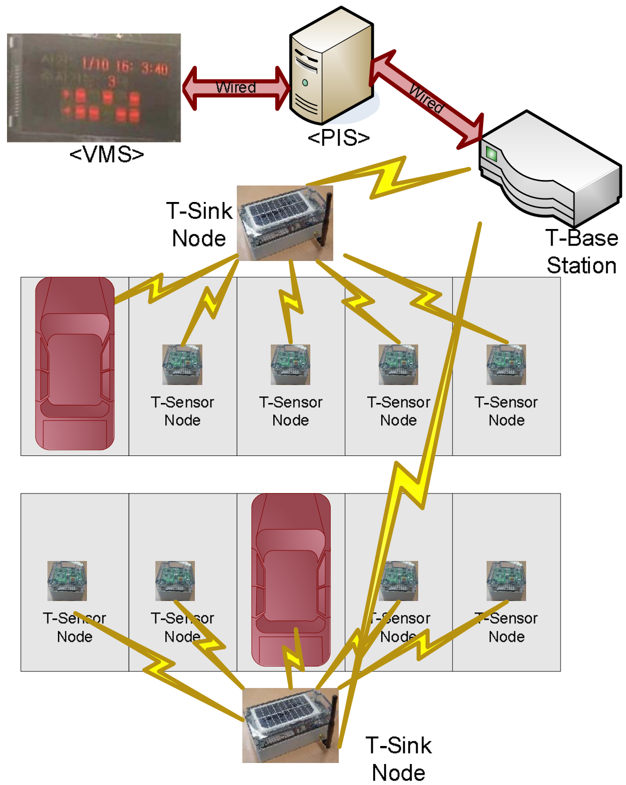

Figure 1. PGS system overview. The system consists of T-Sensor nodes, T-Sink Nodes, T-BS, Display, and PIS

VDS consists of T-Sensor nodes, T-Sink nodes, and a T-BS. Each T-Sensor node has a magnetic sensor to detect ferrous materials in a vehicle. When a car approaches a parking lot, T-Sensor node detects the car and notifies the detected events to the T-Sink node. The T-Sink node will then forward the detection event to the T-BS. When the car is moving out from the parking lot, the event is detected by T-Sensor node and forwarded by T-Sink nodes. The details of the routing protocol are explained at the end of this section.

A. T-Sensor Node

T-Sensor node is used to detect a vehicle approaching the sensor node and to report the event to the T-BS via T-Sink nodes. When the vehicle is moving out of the parking lot, the T-Sensor node detects the event and reports it to T-BS as well. Fig. 2 shows the hardware block diagram of the T-Sensor node and Fig. 4 is a photo of an assembled T-Sensor node. The T-Sensor node has an Atmega128L MCU and a CC2420 IEEE 802.15.4 compliant transceiver. The T-Sensor node is equipped with a magneto-resistive sensor to detect ferrous materials in a vehicle. Taking into consideration that the Earth's magnetic field varies in different positions, we designed a gain block and a calibration block for the sensor. The software of the T-Sensor node consists of T-FRAME and T-Sensor application software(Fig. 3). T-FRAME is a basic software frame for TSN (Telematics Sensor Network) which is developed by us. T-FRAME consists of a HAL (Hardware Abstract Layer), MAC (from Chipcon MAC v.0.7), and tree-based multi-hop routing. The most important block in T-Sensor application software is the parking decision block.

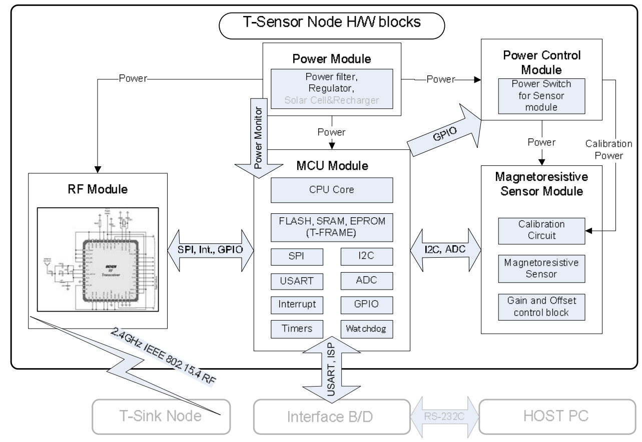

Figure 2. T-Sensor node hardware block diagram

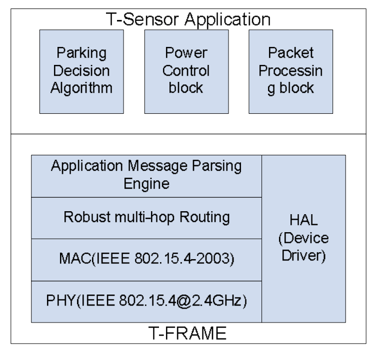

Figure 3. T-Sensor node software block diagram

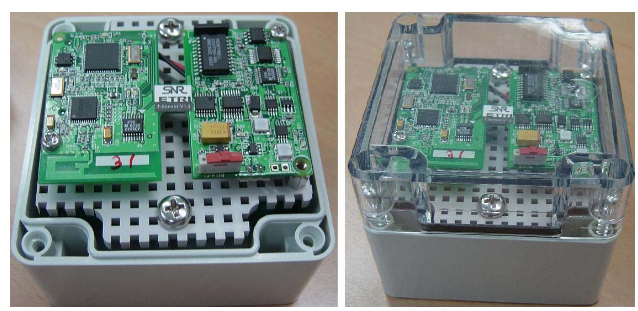

Figure 4. Assembled T-Sensor node

The parking decision block consists of a vehicle detection state machine and a calibration algorithm. The vehicle detection state machine determines the occupancy of the parking lot with the past N instant detection flags. An instant detection flag is acquired by comparing the sample value to the detection threshold. If the last instant flags are set to 'detect' for the specified time *Ld* seconds, the state is changed to 'occupied'. If the last instant flags are set to 'no car' for the specified time *Ld*, the state is changed to 'vacant'. This is a simple state machine based vehicle detection algorithm. With adaptive sampling such as Fig. 5, the state machine can be more power-efficient and more accurate. The calibration algorithm is to calibrate the sensor periodically and compensate for the thermal drift of the sampling values to acquire more accurate and sensitive sample values.

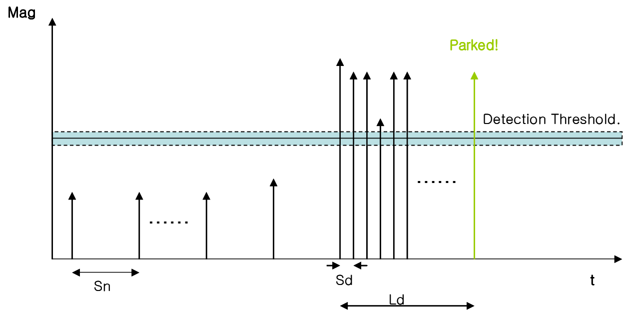

Figure 5. Adaptive Vehicle Detection Algorithm. *Sn* is the normal sampling period. *Sd* is the detecting sampling period. *Ld* is detection latency.

B. *T-Sink Node and T-BS*

T-Sink nodes are used to gather events from T-Sensor nodes, and to forward the events to T-BS. The hardware block diagram of T-Sink nodes is similar with that of the T-Sensor. T-Sink node has an Atmega128L MCU and a CC2420 IEEE 802.15.4 compliant transceiver with a 10dBm external power amplifier (PA) to extend the communication range. Each T-Sink node is equipped with a recharging circuit and a solar panel. Fig. 6 shows an assembled T-Sink node. The software of T-Sink nodes consists of T-FRAME and T-Sink application software. T-FRAME used here is the same as the one mentioned in the previous sub-section. T-Sink application software includes a management software block which manages the T-Sensor nodes and keeps track of management information such as remaining battery levels. T-BS is equipped with a T-Sink node to communicate with the other T-Sink nodes and gather information from T-Sensor nodes via T-Sink nodes and to manage the WSN. In addition, T-BS is a gateway between the WSN and conventional internet and is connected to the PIS via internet.

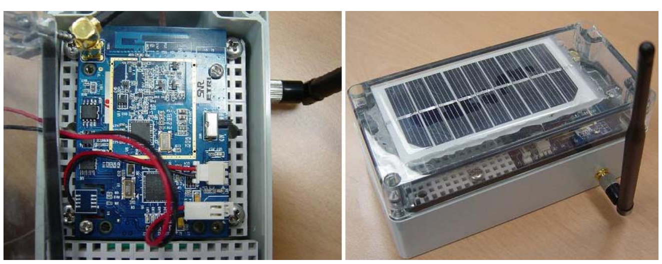

Figure 6. Assembled T-Sink node

C. *Robust Multi-hop ad-hoc routing*

A T-Sensor node is always an end device, which does not have any child node, and joins to a T-Sink Node. To simplify the route discovery, a tree-level which is the same as hop count from T-BS is preprogrammed in the on-chip EEPROM with a network-wide unique 16bit address. The level of T-BS is '0', level '1' is assigned to the immediate children of T-BS, level '2' is assigned to the grandchildren of T-BS, and so on. When T-Sensor or T-Sink node initializes its parent-child relationship, it begins the joining process by broadcasting the 'search parent' packet including a cost function, in this case its tree-level. Whenever T-Sink node receives the 'search parent' packet, it checks the cost function and unicasts the 'invite' packet to the joining node if the received tree-level is one-level larger than it own tree-level. For a specified time, the joining node waits for the 'invite' packets from the prospective parent nodes and stores the RSSI values of the 'invite' packets. After the specified time, the joining node chooses its parent according to the cost function, in this case the largest RSSI value, and sends the 'join' packet to its parent. The sensor node which receives the 'join' packet adds the joining node to its children list. Finally, the joining process is finished and the parent-child relationship is established. If the parent of a T-Sink node or a T-Sensor node does not reply with any ACKs despite retransmissions, the parent node is considered to be dead and the child node initiates the joining process by trying to search for a new parent with an immediate lower tree-level as quickly as possible.

III. RESULT AND DISCUSSIONS

We implemented PGS system and conducted several experiments with them in our testbed. We explain the experimental results and discuss them in this section.

A. *Communication Module*

1) *Transmission Power*

We modified TI's design for an external 10dBm PA block (@3.3V operation voltage). Using the single-tone generation mode of CC2420, we measured the un-modulated peak transmission power with a spectrum analyzer as shown in Fig. 7. Instead of a 3.3V operation voltage, our implementation uses 3.2V and has a transmission power of about 7dBm. For a reference, TI's CC2420EM could send up to -1.6dBm.

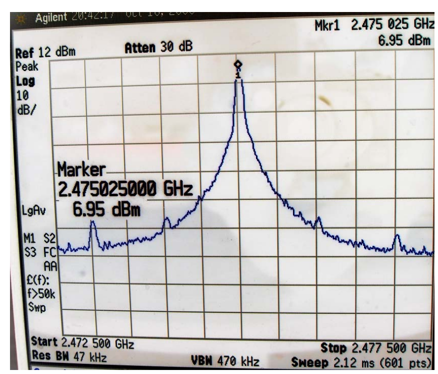

Figure 7. Single-tone transmission power of T-Sink node

2) *Routing Algorithm*

We implemented the robust multi-hop ad-hoc routing algorithm and experimented on the implementation. Considering T-BS as level of 0, We set the network topology so that The level of T-Sensor node is '2'. According to our experiment, the algorithm worked well and a T-Sensor node could join to a T-Sink node which was nearer to it. Whenever we turned off the parent node, the child node could search for parent candidates and join the new parent with the highest RSSI among the candidates. Although there is about 400msec. latency to recover the routing path, the latency is not so critical in PGS in comparison with the time critical DGS[11].

B. *Vehicle Detection*

The T-Sensor node is designed to detect the approach or moving-out of a vehicle. Fig. 8 shows the distortion of the earth magnetic field when we pass a vehicle over a T-Sensor node. The easiest way to detect a vehicle is to measure the magnitude of magnetic variation of the distortion from the base-line (in this case 440 units). We implemented state-machine based vehicle detection algorithm as explained in section 2.

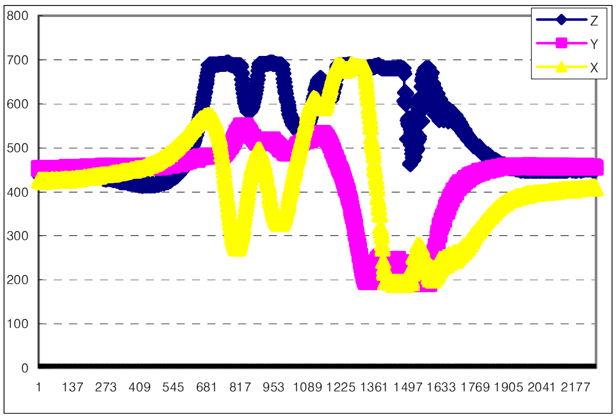

Figure 8. . Magnetic field distortion by a ferrous object such as a car

C. *Demonstration in parking lots*

We deployed 10 T-Sensor nodes and 2 T-Sink nodes and 1 T-BS and 1 PIS and 1 VMS as Fig. 9. In this demonstration, we used 7 makes of cars to we evaluated the PGS system and demonstrated the performance of the system. PGS could detect the various kinds of cars well.

Figure 9. Demonstration of PGS system. 1) T-Sensor nodes in parking lots, 2) T-Sink Node, 3) 7 cars in the parking lots, and 4)VMS which is displaying the available parking lots(from left-top to left-bottom in clock-wise direction)

D. *Battery-life time estimation*

In our T-Sensor nodes, we did not control the power of each component. However, through analysis and simulation, we estimate the battery life-time of the next version of the T-Sensor node. The following equation (1) is the battery-life time model used in this experiment and Table 1 explains each parameter in the model. *Cs* is the average current consumption for sensing task and includes the current consumption due to sensing with a magnetic sensor and sampling with an ADC of the MCU. *Cp* represents average current consumption for signal processing with the MCU. *Cr* means average current consumption by the RF transceiver, CC2420, and the MCU. *Ci* includes the current consumption of idle task by the MCU.

$$L = \frac{B}{Cs + Cp + Cr + Ci} \quad (1)$$

TABLE I. DESCRIPTION ON THE BATTERY-LIFE TME MODEL

Abbreviation	Meaning
L	Battery life-time of T-Sensor node
B	The battery capacity
Cs	Average current consumption for sensing task
Cp	Average current consumption for signal processing task
Cr	Average current consumption for RF Tx/Rx task(~30mA)
Ci	Average current consumption for idle task(~50uA)

Assuming traffic of 1,440 vehicles/day (about 1 vehicles/minute), we used MATLAB to simulate the battery life-time of T-Sensor nodes versus the amount of traffic. To ensure the accuracy of this simulation, we measured the current consumption profile of our new T-Sensor node instead of using the values in datasheets. Assuming we use single 3.6V, 2400mhA AA sized (Lithium-Ion) battery cells which can keep 80% of their capacity in the real field, we can obtain the battery life-time versus the volume of daily traffic as the shown in Table II. From the result, we know that the life expectancy of our new sensor node is over 5 years with traffic of 1 vehicles/minute.

TABLE II. BATTERY-LIFE TIME VS. TRAFFIC. T-SENSOR CAN RUN OVER 5 YEARS

Vehicles/hour	Vehicle/day	Expected years
0	0	5.3156
6	144	5.3115
12	288	5.3075
18	432	5.3035
24	576	5.2995
30	720	5.2955
36	864	5.2915
42	1008	5.2875
48	1152	5.2836
54	1296	5.2796
60	1440	5.2756

IV. CONCLUSION

We have presented the overall architecture of the PGS which guides drivers to available parking lots. We also explained the experimental result of PGS system implementation. From the result, we show the performance of PGS system. It can detect various kinds of cars and support self-healing when there occur routing problems. With the measured current consumption profile, we performed a series of battery life expectancy simulations. The results show that the battery life expectancy is over 5 years with very heavy traffic.

We are currently developing new T-Sensor hardware with lower current consumption and are planning to make a testbed in ICU. For real deployment, a standard frequency allocation is required and we are working on this based on the standardization.

V. ACKNOWLEDGMENT

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VI. REFERENCES

[1] Vehicle Detection Station Device White Paper, Wilbur Smith Associates/IBI Group, 24, Jan. 2006

[2] S. Yoo, et al., “A2S: Automated Agriculture System based on WSN”, 11th Annual IEEE International Symposium on Consumer Electronics(ISCE2007), Dallas, Texas, 20-23 Jun. 2007.

[3] Jose A. Gutierrez, Edgar H. Callaway, Jr., and Raymond L. Barrett, Jr., Low-Rate Wireless Personal Area Networks: enabling wireless sensors with IEEE 802.15.4, IEEE Press 2004

[4] T. Phan, B.W. Kwan, and L.J. Tung, “Magnetoresitors for Vehicle Detection and Identification”. IEEE International Conference on Systems, Man, and Cybernetics. 12-15 Oct. 1997

[5] Ara N. Kanian, A, “Wireless Sensor Network for Smart Roadbeds and Intelligent Transportation Systems”, Master Thesis. MIT. 2000

[6] S. Yiu, S. Coleri, B. Dundar, S. Ganesh, C. Tan, and P. Varaiya., “Traffic measurement and vehicle classification with a single magnetic sensor”, California Partners for Advanced Transit and Highways (PATH). Working Papers: Paper UCB-ITS-PWP-2004-7, 2004

[7] S. Yiu, S. Coleri, and P. Varaiya, “Traffic Surveillance with Wireless Magnetic Sensors”. 12th ITS World Congress, San Francisco, Nov. 2005

[8] J. Ding., S. Yiu, C. Tang, and P. Varaiya, “Signal processing of sensor node data for vehicle detection”. 7th International IEEE Conference on Intelligent Transportation Systems. IEEE, 2004

[9] S. Coleri, and P. Varaiya, “PEDAMACS: Power Efficient and Delay Aware Medium Access Protocol for Sensor Networks”, IEEE Trans. Mob. Computing 5(7): 920-930 2006

[10] J. Sung, et al., “Wireless Sensor Network for Cultural Property Protection", 1st IEEE International Workshop on Applications of Ad hoc and Sensor Networks(AASNET2008, in conjunction with AINA2008), Okinawa Japan, 25~28 Mar., 2008, in press

[11] S. Yoo, et al., “DGS: Driving Guidance System based on Wireless Sensor Network", 1st IEEE International Workshop on Applications of Ad hoc and Sensor Networks(AASNET2008, in conjunction with AINA2008), Okinawa Japan, 25~28 Mar., 2008, in press