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DGS: Driving Guidance System based on Wireless Sensor Network

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Abstract

In this paper, we present DGS, a Driving Guidance System based on wireless sensor networks(WSN) which guides a driver to drive a car in safety. The system consists of two sub-systems: SMS(Speed Measurement Sub-system) and WPS(Weather information Providing Sub-system). SMS measures the speed of a car and captures the image of the speeding car using a speed camera. WPS provides weather information including the road conditions (icy, wet, etc.) via VMS or a telematics terminal. The paper describes the overall system architecture of DGS from the hardware platform to the application software in the view point of a WSN. We implemented the WSN based SMS of DGS from hardware to application software. The experimental results show that the accuracy of speed measurement is over 99% at 80kmph and the predicted battery life-time using measured current profiles is about 3 years. We also discuss the lessons acquired from the real-life experiments we performed. We believe that the lessons can be useful in other WSN applications as well as in typical telematics applications.

1. 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 networks(WSN) are 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, 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 for safe driving. Currently, these information are detected in a wired way using loop detectors and sensors. 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 and speed measurement. T. Pham, et. al modeled the combined induced magnetic field and the permanent magnetic field of a vehicle in motion as a moving magnetic dipole[4]. Through computer simulation, they showed a vehicle detection and identification based on a small magnetic sensor. Ara N. Knaian introduced a wireless sensor package(i.e. sensor node) to detect a vehicle in his master thesis[5]. The sensor package included two sensors to measure the speed and a transceiver using the 915MHz band to report the sensing result to a PC. He designed the sensor package from antenna to system software. In addition, he analyzed the battery life-time and cost to build the sensor package. Sing Yiu Cheung, et.al published papers on traffic measurement and classification with magneto-resistive sensors[6][7]. They proposed a hill-pattern based vehicle detection and classification algorithm and number of experimental results. Jiagen Ding, et. al proposed signal processing algorithm for vehicle detection based on acoustic and magnetic sensors and described their experimental workings[8].

Here, we present the WSN based DGS system architecture which consists of the SMS and the WPS.

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The WPS is used to provide road condition information (e.g., dry, icy, wet, etc.) to drivers and the SMS is used to measure the speed of a vehicle and to control a VMS(Variable Message Signboard) or a speed camera to guide the driver to keep to the regulated speed. The contributions of our paper are summarized as follows. The system architecture for DGS is presented in all aspects from the sensor/actuator/sink node hardware at the bottom to the management sub-system at the top and is evaluated in a testbed which is located in a part of an old Gyeongbu(Seoul-Busan) Expressway. The accuracy of the speed measurement from the experiment is measured and the result shows over 99% accuracy at 80kmph. Using the measured current profiles from the sensor nodes, we show through simulation that the life expectancy of a sensor node placed on the busiest road in Korea, with an average daily traffic of 160,000 vehicles, is about 3 years.

The rest of this paper is organized as follows: Section 2 describes the system architecture of DGS 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.

2. System Description

In this section, we describe the whole DGS system including WPS and SMS, focusing on WSN.

2.1. WPS

The WPS(Weather Information Providing Sub-system) provides weather information near a roadway. The WPS sub-system consists of W-Sensor nodes, W-Sink nodes, a W-BS (such as ANTS-H4[9]), and a WIS(Weather Information Server). The W-Sensor nodes are installed at the side of the roadway and gathers information on the condition of the surface and the visibility of the roadway (e.g. icy, wet, foggy, etc.). Since W-Sensor nodes can be attached with several accurate but energy intensive sensors, solar cells are usually used to recharge the battery. Although a WSN can be formed by just using W-Sensor nodes alone, in normal operations, W-Sensor nodes are usually used with W-Sink nodes that collect and forward information from the W-Sensor nodes to a W-BS, which is equipped with a long range transmission equipment such as a CDMA modem. The weather information that has been gathered is then transmitted from the W-BS to the WIS and there, it is refined and provided to drivers in various ways. Figure 1 shows the WPS.

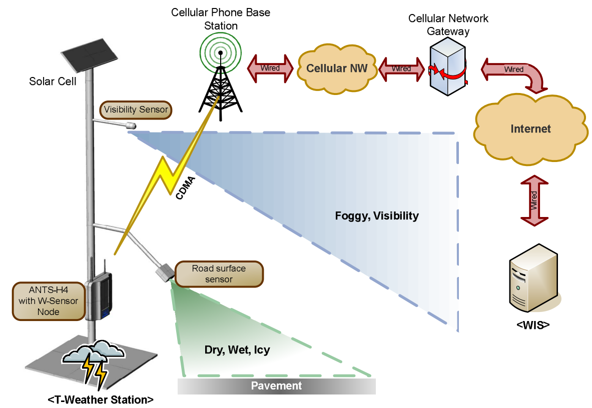

Figure 1. WPS overview. The system consists of W-Sensor node, W-Sink node, W-BS, and WIS

2.2. SMS

SMS(Speed Measurement Sub-system) is designed to measure the speed of a vehicle and to notify the driver of the speed. SMS consists of T-Sensor nodes, T-Act nodes, T-Sink nodes, a T-BS, and a TIS(Telematics Information Server). Each T-Sensor node has a magnetic sensor to detect ferrous material on vehicles. When two consecutive T-Sensor nodes detect a vehicle, they notify the detected events to the T-Sink node. The T-Sink node will then calculate and send the measured speed to the T-Act node. The T-Act node will then control a VMS (Variable Message Signboard) to provide the speed information to the driver or to control a speed camera to take a photo of the speeding car. The following Figure 2 shows the overview of the SMS sub-system. In this section, we explain the WSN part of the SMS sub-system in detail.

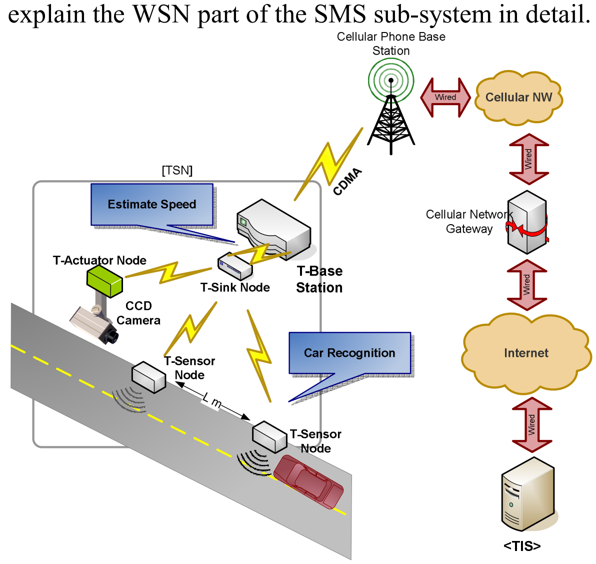

Figure 2. SMS overview. The system consists of T-Sensor nodes, T-Sink nodes, T-Act nodes, a T-BS, and a TIS

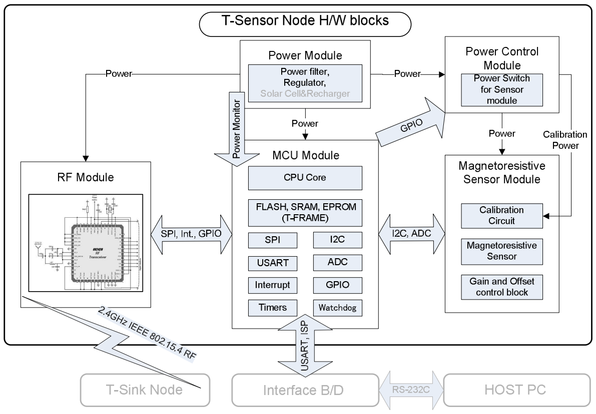

Figure 3. T-Sensor node hardware block

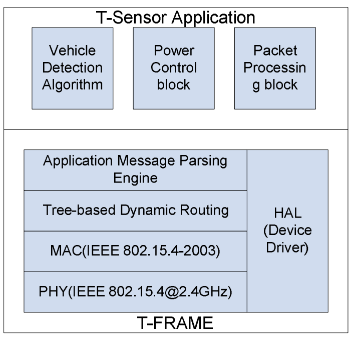

Figure 4. T-Sensor node S/W block diagram

2.2.1. T-Sensor Node. The T-Sensor node is used to detect vehicles approaching the sensor node and to report the events to the T-Sink node as soon as possible. Figure 3 shows the hardware block diagram of the T-Sensor node and Figure 5 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 on different roads, 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(Figure 4). 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 routing (explained in the following sub-section). The T-Sensor application software includes a calibration block and a vehicle detection block.

2.2.2. T-Sink Node & T-Act Node. T-Sink nodes are used to gather events from T-Sensor nodes, and to manage or control T-Sensor and T-Act nodes. 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). T-Sink node is equipped with a recharging circuit and a solar panel. Figure 6 shows the assembled T-Sink node. The hardware block of the T-Act nodes is similar with that of the T-Sink node except for additional GPIO and RS-232 interfaces to control a VMS or a speed camera. The software of T-Sink (or T-Act) nodes consists of T-FRAME and T-Sink (or T-Act) 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. The application software of T-Act nodes is used to listen for commands from T-Sink nodes and to control a VMS or a speed camera.

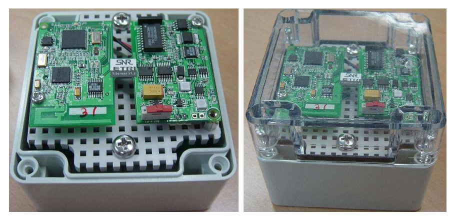

Figure 5. An assembled T-Sensor node.

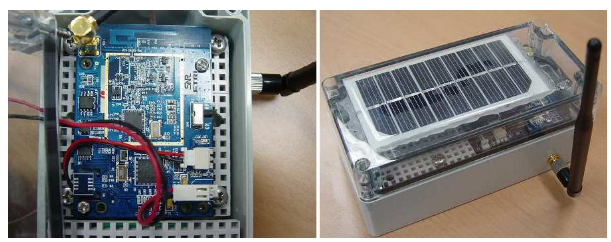

Figure 6. . An assembled T-Sink node.

2.3. Dynamic Multi-hop ad-hoc routing

In this sub-section we present a routing protocol which is specially designed for our application. The routing protocol consists of two levels of hierarchy. One is T-Sink (or W-Sink) to T-Sink (or W-Sink) routing and the other is T-Sink to T-Sensor node routing.

The routing between T-Sink nodes is designed to include both dynamic addressing and dynamic routing. In the case of the dynamic addressing, we employ 16-bit network address besides an extended 64-bit IEEE MAC address at each sensor node. The 16-bit network address is dynamically assigned to each T-Sink node when they form a tree topology. Figure 7 represents the detailed algorithm of our addressing scheme. In the figure, *MC* represents maximum number of child nodes that a parent can have, and *Ap* represents the address of the parent node. By using a different 16-bit short address scheme in the network layer, we can efficiently use limited address space and reduce the size of packets by 48 bits (64 bits minus 16 bits). When T-Sinks are initially deployed in the field, they start to form a minimum spanning tree by broadcasting routing packets. The address of each node is determined at this stage. Therefore, the network topology is never deterministic but always dynamically changing to construct optimized routing paths for different environments.

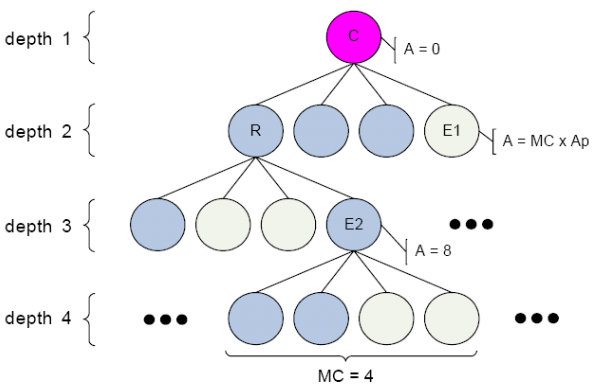

Figure 7. Dynamic Addressing scheme.

However, the routing between T-Sink nodes and T-Sensor (or W-Sensor) nodes is static so parent-child relationships between T-Sink and T-Sensor nodes must be manually determined before deployment. Therefore, T-Sensor nodes can only transmit their data to their designated T-Sink nodes. Since we use a pair of T-Sensor nodes to detect the speed of the car, we can reduce the complexity by statically combining two T-Sensor nodes and their immediate parent, the T-Sink node.

3. Result and discussions

We implemented part of the DGS system and the full multi-hop routing and SMS sub-system and we conducted several experiments with them in our testbed which is located in a part of an old Gyeongbu(Seoul-Busan) Expressway. We demonstrate the experimental results and discuss them in this section.

3.1. Vehicle Detection

The T-Sensor node is designed to detect a vehicle and to measure the speed of the vehicle with the cooperation of another T-Sensor node, a T-Sink node, and a T-BS. Figure 8 shows the distortion of the earth magnetic field when we pass a ferrous object 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)

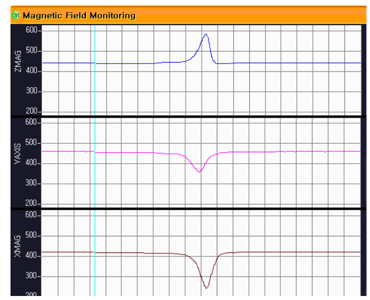

Figure 8. Magnetic field distortion by a ferrous object

3.2. Accuracy of speed measurement

To measure the speed of a vehicle, we separated two T-Sensor nodes by a known distance, in this case, it was 8m. We used a Grand Carnival, a SUV of from KIA Motors for this test. Figure 9 compares the measured speed from two T Sensor nodes to the speedometer in the dashboard of the car. The top and bottom row of numbers at the bottom of the graph are the speed of the car as shown on the speedometer and the speed measured by T-Sensor nodes respectively.

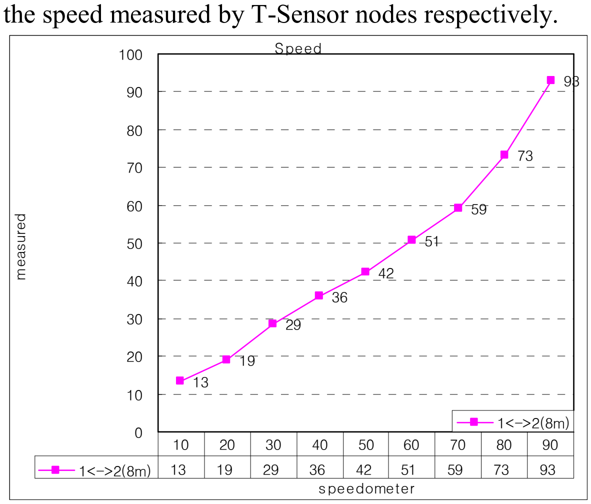

Figure 9. speed measurement between 10~90km/h-Dec. 2006

Since the results seem to imply that the measurement of the T-Sensor nodes are inaccurate, we checked and found out that speedometers are required by law to err on the high side of the real speed of the vehicle in Korea [10] and this is probably the case for the rest of the world as well. This means that the speedometer's reading should always be the same or higher than the real speed but never lower. The results from the tests show that the speeds measured by the T-Sensor nodes are generally lower than those recorded on the speedometer.

To determine the real accuracy of the T-Sensor nodes, we performed the speed measurement test again and used a speed radar gun to measure the speed of the vehicle. The 2 T-Sensor nodes were separated by a smaller distance compared to the previous test and we used additional types of vehicles for this test, such as a passenger car and a jeep. Figure 10 shows the results of the speed measurements by the T-Sensor nodes and the speed radar gun. The results of the speed measurement show that the T-Sensor nodes are highly accurate without any dependency on the type of vehicles. The maximum difference between the T-Sensor nodes and the speed radar gun for all speeds tested was 4 km/h, while the minimum difference was 0km/h.

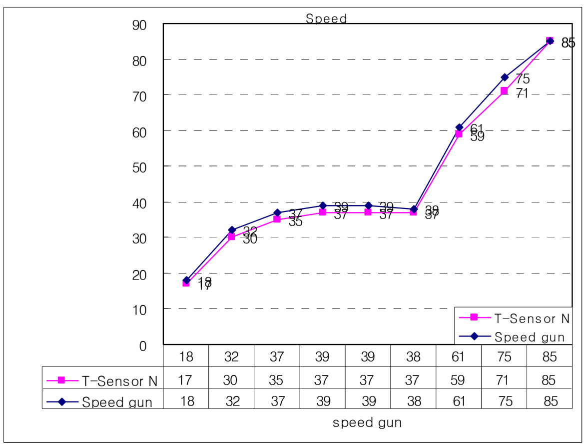

Figure 10. Speed measurement T-sensor nodes vs. speed gun - Jan. 2007

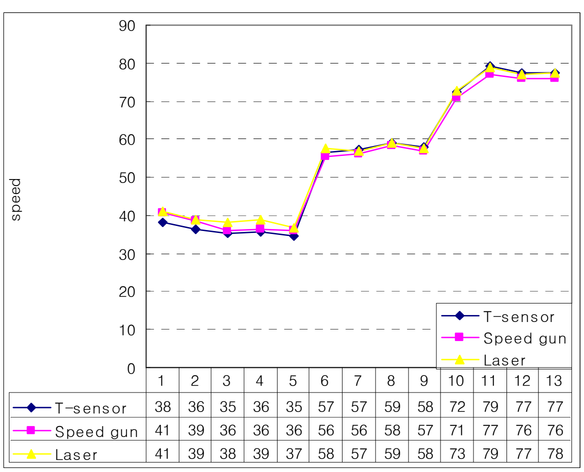

Figure 11. Speed measurement T-sensor vs. speed gun vs. laser machine-Jan. 2007

We prepared a final test with 6m separation to confirm the performance of our SMS through the use of a laser machine(Figure 11). To evaluate the accuracy of the SMS, we calculated the MAPE (Mean Absolute Percentage Error) using (1). SMS was shown to perform with an accuracy of 92.0%, 99.2%, 99.5% at 40kmph, 60kmph, 80kmph, respectively. The MAPE of the whole test is 96.9%.

$$MAPE = \frac{1}{n}\sum_{i=0}^{n-1}\frac{|a_i - b_i|}{a_i}\times 100, \quad (1)$$

$\text{where } a_i \text{ is taken from the laser speed machine}$
$\text{and } b_i \text{ is the measured value from SMS sub-system}$

3.3. Battery-life time evaluation

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 (2) is the battery-life time model used in this experiment and Table 1 explains each parameter in the model.

$$L = \frac{B}{Cs + Cp + Cr + Ci} \quad (2)$$

Table 1. Description on the battery-life time model

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

From the annual traffic census in 2006, the average traffic in the busiest road in Korea is about 160,000 vehicles/day (about 1.9 vehicles/second). Assuming this amount of traffic, 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, taking into consideration a maximum detectable speed of 200kmph. Assuming we use several 3.6V, 2400mAh 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 Figure 12.

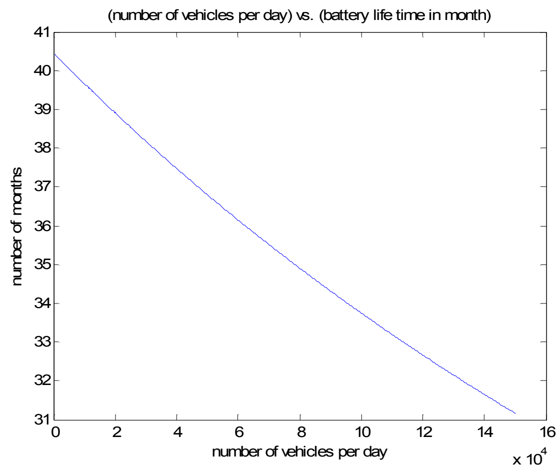

Figure 12. Battery-life time vs. daily traffic. T-Sensor node can run over 3 years

From the result, we know that the life expectancy of our new sensor node is over 3 years with traffic of 1.9 vehicles/second.

4. Conclusion

We have presented the overall architecture of DGS system which helps drivers driving cars with weather information and speed information. We have explained the experimental result of SMS sub-system implementation. From the result, we show the accuracy of the speed measurement is over 99% at 80kmph. With the measured current consumption profile, we performed a series of battery life expectancy simulations. The results show that the battery life expectancy is about 3 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. To deal with a large number of SMS sub-systems in the same radio space, we are currently working on a real-time MAC algorithm. For the real deployment, a standard frequency allocation is required and we are working on this based on the standardization..

5. Acknowledgment

Tomás Sánchez López from RESL gave us many useful comments when we were designing the system architecture. Jinsung Noh from SNR Inc. gave us valuable advices on the real field environment.

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