IP-based Wireless Sensor Networks Infrastructure for Smart Highway

Sungmin Hong[1], Wooyoung Jung[1], Daeyoung Kim†, Youngjin Kwon[2], and Daekyo Jung[3]
[1]Information and Communications University
[2]Sensor Networks Research Inc.
[3]Korea Telecom Corp.
{ghitsh, sida37, kimd}@icu.ac.kr, kyj@snr.kr, dave@kt.co.kr

***Abstract*—Smart Highway is a next generation road that significantly improves the traffic flow, convenience, and safety at high speeds over 160 kilometers per hour. In order to achieve the goal, the smart highway requires collecting a large amount of information including road conditions, environment, vehicle status, driver's condition, and other useful data. In this regard, wireless sensor networks can be an appropriate solution since they were born for the purpose. However, existing wireless sensor networks, such as ZigBee and other legacy sensor networks, have difficulties in constructing a global infrastructure for the smart highway. We thus propose an IP-based wireless sensor networks infrastructure as an optimal solution for the smart highway. This paper shows its suitability, service model, and architecture, and then describes our implementation of a test bed and evaluation. We finally conclude with remaining issues for further research.**

***Index Terms*—6LoWPAN, ITS, Sensor Networks, Smart Highway**

I. Introduction

SMART highway is a project run by the Korean government to build a next generation intelligent highway. It is rooted from ITS (Intelligent Transportation System) enabling drivers to keep focusing solely on driving at speeds over 160 kilometers per hour; its aim is to guarantee smooth traffic flow and minimize accidents by integrating various cutting-edge technologies into it. Thereby, the government expects it to increase the mobility of vehicles and energy efficiency, and play an important role as an IT (Information Technology) test bed.

Building a smart highway system basically requires data such as traffic flows, traffic control, accidental circumstances, road conditions, and weather. Gathering the data and transforming them into useful information also need to integrate IT-related high technologies with the smart highway system. There exist diverse ITS technologies which can be applied to the system as a solution; however, recently emerging technologies, in particular wireless sensor networks for facilitating many kinds of environmental data around roads and WiBro (Wireless Broadband) for a reliable vehicle-to-vehicle communication between fast moving vehicles, can offer more promising solutions than the existing technologies can. In this paper, we focus on wireless sensor networks to build an infrastructure for the smart highway as an optimal solution which replaces the legacy wired networks suffering from several known problems, such as difficult installation, cost of maintenance, lack of scalability, and other drawbacks, in measuring road and weather conditions and observing traffic flows and speeds of vehicles around the high-speed roads.

Wireless sensor networks, as a chief component of the smart highway, vary from non-standard to standard protocols. For instance, there are legacy wireless sensor networks, such as TinyOS [1], ANTS [2], and other proprietary senor networks, and ZigBee [3] standard. However, both wireless sensor networks solutions are originally designed on a non-IP (Internet Protocol) and local network basis. They thus have in-born difficulties in connectivity, interoperability, and compatibility with heterogeneous networks. Sensor nodes are hardly allowed to communicate with peers outside the local network. Indeed, they can support connecting sensor networks to the Internet and other sensor networks somehow via proxy-based approaches but additional works should be taken care of, such as translation between IP and local network protocols; however, they are not yet seamless.

In this paper, we propose IP-based wireless sensor networks (IP-WSN) as an infrastructure for the smart highway. IP-WSN meets 6LoWPAN specifications [4] which define how to harness IPv6 packets over IEEE 802.15.4 networks. Each sensor node in IP-WSN has a globally unique auto-configured IPv6 address and is transparently connected to the Internet with TCP/IP protocols through 6LoWPAN adaption layer and a lightweight TCP/IP stack. Unlike the non-IP based wireless sensor networks, IP-WSN leverages great advantages of existing Internet standards rather than recreating similar works for the same purpose.

The proposed infrastructure for the smart high facilitates the advantages of IP-WSN as shortly described above. In this paper, we present what IP-WSN is about and what benefits it takes in detail; we then propose the entire architecture and services of the smart highway based on IP-WSN in section II. In section III, we describe implementation details of an IP-WSN test bed as an interim process for constructing the whole infrastructure. Section IV includes performance results of the developed test bed deployed in the KOREN [5]. Finally, we conclude with

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (No. R0A-2007-000-10038-0) and Korea Telecom (KT).

† *Corresponding author*: School of Engineering, Information and Communications University, Associate Professor

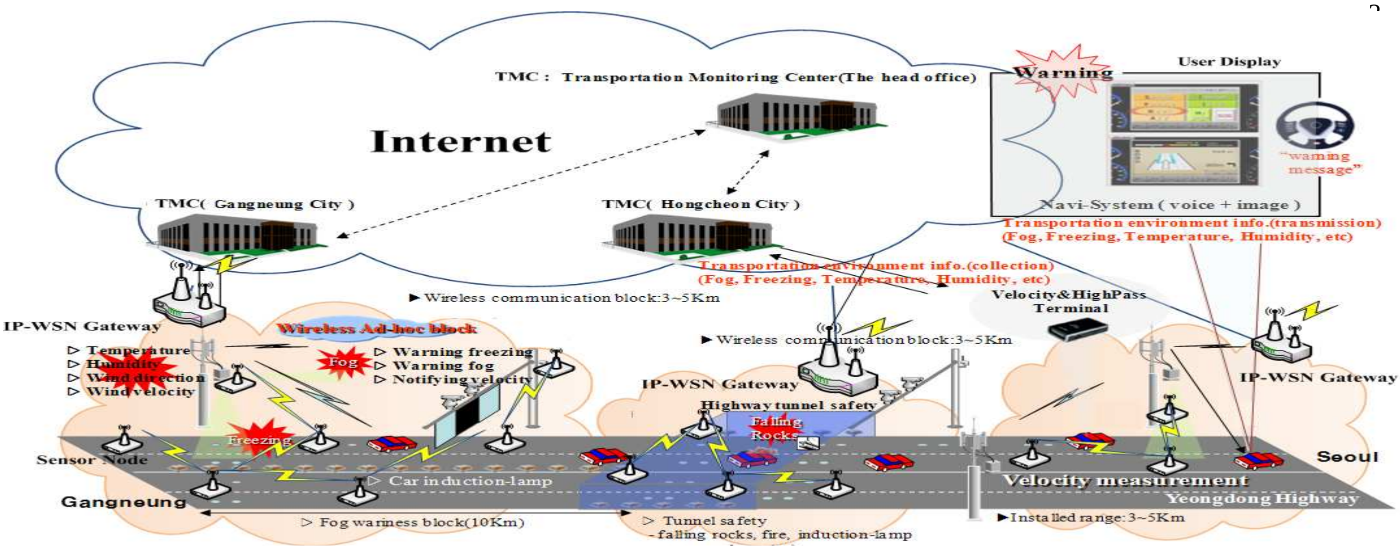

FIGURE 1. IP-WSN INFRASTRUCTURE FOR SMART HIGHWAY

remaining issues for further research.

II. IP-WSN INFRASTRUCTURE FOR SMART HIGHWAY

A. IP-based Wireless Sensor Networks

IP-WSN (IP-based wireless sensor networks) is the low-power wireless personal area network equipped with IP connectivity between sensor nodes and any IP-enabled devices including mobile handsets, PCs, servers, and other devices deployed in different networks as well as same networks using standard Internet protocols. A sensor node acquires a unique IPv6 address and connects to the Internet via IP-WSN gateway. IP-WSN is based on 6LoWPAN standards by IETF 6LoWPAN working group [4] who standardized RFC4944 [6] and RFC4919 and has been proposing various. In addition, a new working group, ROLL (Routing Over Low power and Lossy networks), is making efforts to provide an independent IP-based routing solution for low-power and lossy networks. Recently, many researchers and companies including ArchRock, Cisco, Dust Network, and other organizations are lively participating in standardization activities. Those working groups' efforts are based on the fact that the size of a network stack, compressed packet length, and energy overhead are reasonable compared to ZigBee [7]; moreover, the advantages of IP-WSN outweighing its drawbacks can get rid of possible worries on it.

B. Smart Highway Infrastructure

Smart highway is a future high-speed road reducing accident rates and supporting intelligent and convenient environment to drivers by providing road, vehicle, environmental, and human information related to driving so that the drivers can concentrate solely on their driving. Many countries in the world have invested aggressively in ITS research realms. The Korean government also plans to construct the smart highway in which the traffic speed is over 160 Km/h guaranteeing minimized accident rates.

To construct the smart highway, it is important to gather useful data such as road conditions, environment, conditions of drivers and cars, and other environmental factors to determine circumstances which can cause accidents and provide drivers with more convenient and safer ambiance. In this regard, wireless sensor networks can offer a well-suited solution for this purpose. Legacy wireless sensor networks, however, have several well-known limitations: local-scope network, no standard protocol, high cost and effort to implement and integrate, and other drawbacks. Therefore, we have designed the IP-based wireless sensor networks infrastructure for the smart highway so that all the sensor nodes and the system can connect transparently each other based on the standard Internet Protocols and facilitate their advantages.

In the IP-WSN infrastructure, numerous sensor nodes equipped with different kinds of sensors are deployed around roads to collect information of freezing, falling rocks, temperature, humidity, fog, fire, wind direction, wind velocity, velocity of the cars, and other useful environment. They then form an IP-based wireless personal area network and start monitoring environment to provide drivers with the collected information. Each sensor node has its own auto-configured IPv6 address so that it can be globally accessible; thereby, a sensor node can communicate with the transportation monitoring center, car system, and user display (Figure 1) via the Internet.

As shown in Figure 1, we have designed the IP-WSN infrastructure for the smart highway from Gangneung city to Seoul city in Korea. The infrastructure mainly consists of three parts: 1) TMC (Transportation Monitoring Center), 2) IP-WSN, 3) User Display. Firstly, TMC is the integrated monitoring system whose aim is to collect all the data from sensor nodes in local IP-WSNs, generate context-aware information, and provide users with advanced services. The TMC is hierarchically configured; each city manages one or more TMCs and each TMC is communicated with a central TMC. Secondly, IP-WSNs are deployed all sides around roads. Each IP-WSN comprises an IP-WSN gateway, router nodes, and sensor nodes. The gateway connects IP-WSN mesh networks to the Internet via Wi-Fi/Ethernet/WIBRO/HSDPA interfaces. The router nodes with rich resources not only forward packets in the middle of a path, but also have responsibility for expanding communication coverage, acting as a proxy directory agent, and helping neighbor discovery and time synchronization overhead decreased on behalf of a PAN coordinator. The sensor nodes are battery-powered devices equipped with various kinds of sensors to gather environmental data including temperature, humidity, wind direction, wind velocity, fog, vehicle velocity, falling rock, camera, fire detection, and other environmental sensors; in addition, the actuators incorporate induction lamps, velocity displays, warning displays, warning lamps, and other devices. Thirdly, a user display is a device that shows real-time information to help users drive safe and comfortable. The user display connects to the TMC via HSDPA/WIBRO interfaces to retrieve real-time information. The TMC transmits environmental information, such as whether condition, road condition, danger zone, traffic information, and frequent accident area, to drivers in a moving vehicle. The user display provides a graphical user interface based on geographical information system and multimedia to offer more convenient and visualized information.

III. Implementation

We have implemented an IP-WSN test bed first as a interim process to build the entire IP-WSN infrastructure for the smart highway. Constucting the test bed is one of the most significant work which should be performed before deploying the IP-WSN on the target roads. Our indoor IP-WSN test bed has been built in KOREN (KOrea advanced REsearch Network) [5] to verify and validate its stability and performance of IP-WSN infrastructure for the purpose.

A. *IP-WSN Sensor Node*

Our IP-WSN sensor node runs on two different platforms which are OSAL (Operating System Abstraction Layer) of TI (Texas Instruments Inc.) solution and ANTS EOS [2] of RESL (Real-time and Embedded Systems Laboratory) in ICU (Information and Communications University). This paper handles implementation on the former platform.

a. Software

IP-WSN sensor node software meets RFC4944 and RFC4919 whose subjects are “Transmission of IPv6 Packets over IEEE 802.15.4 Networks” [6] and “6LoWPAN: Overview, Assumptions, Problem Statement and Goals” in order. As shown in Figure 2, a 6LoWPAN adaptation layer locates between a network manager and a lightweight TCP/IP stack. Our implementation of 6LoWPAN adaptation layer meets RFC4944; however, fragmentation/reassembly was excluded. It is mainly because we set it as the lowest priority of implementation for the reason that normal sensor network applications do not require a large frame size to collect and handle sensing data from sensor nodes. The left stack in Figure 2 depicts the IP-WSN sensor node network stack and boxes in white mean unimplemented components in this paper.

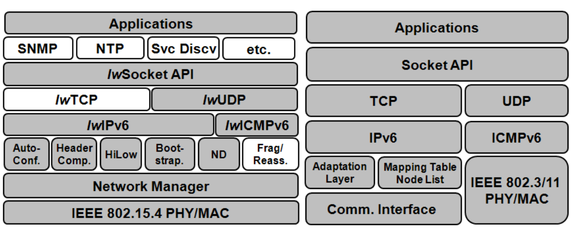

Figure 2. IP-WSN Sensor Node and Gateway Network Stack

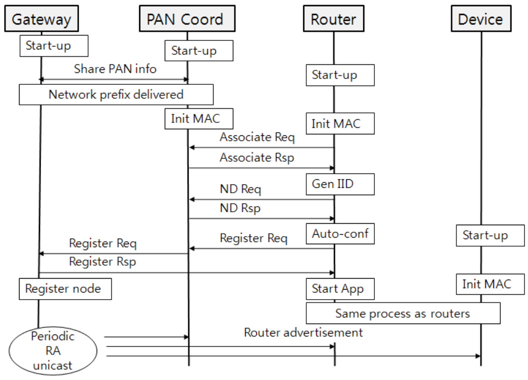

Figure 3. Bootstrapping and Route Advertisement

Regarding routing protocol, we have implemented HiLow routing protocol, i.e. tree routing protocol, which is an expired 6LoWPAN draft. There are three proposed routing protocol drafts which are HiLow, LOAD, DYMO-low. However, none of them has been standardized so far. In this paper, we chose HiLow routing protocol based on width-first algorithm due to its salability, convenient address structure to manage the sensor networks by using a 16-bit short address, and no need to maintain a routing table.

The auto-configuration is performed in the process of so-called bootstrapping. The optimization of ND (Neighbor Discovery) of IPv6 has been being discussed in the 6LoWPAN working group; though, it has not been standardized yet, neither has bootstrapping. We have designed our own bootstrapping and network prefix advertisement mechanism. As shown in Figure 3, auto-configuration is performed just after an association process between two nodes and the joining node then registers itself to a PAN Coordinator so that the PAN coordinator can manage all the registered nodes in a PAN and advertise the network prefix periodically. From this method, the overhead of multicast messages of ND can be considerably reduced since only unicast messages are utilized in the process.

The components of our embedded TCP/IP stack support a lightweight IPv6, ICMPv6, and UDP which are in gray in Figure 2. Especially, ICMPv6 supports echo request/reply messages and neighbor discovery messages. TCP protocol is in the progress of implementation and security service and other useful protocols—SNMP, NTP, Service Discovery, and etc—are further research topics.

b. Hardware

We have developed IP-WSN sensor node hardware shown in Figure 4. The sensor node hardware includes MSP430FG4618 MCU, 8KB RAM, 116KB flash memory, and CC2420 RF. It is powered by two AA-sized batteries and contains one USB port for communication between IP-WSN coordinator and IP-WSN gateway and debugging.

B. *IP-WSN Gateway*

The implemented gateway was designed to handle basic requirements of IP-WSN and further research topics with rich resources. We describe the details as follows.

a. Software

The IP-WSN gateway has three major roles: 1) IPv6 packet delivery from the Internet to the corresponding sensor node and vice versa; 2) network prefix handling; 3) network management. For the first role, the gateway supports an IPv6 stack at least as well as IPv4 stack since IP-WSN is based on IPv6. Because IPv6 networks are not fully deployed throughout the world; that is, IPv6 should be delivered not only in IPv6 networks by default, but IPv6 packets should also pass through the IPv4 networks. For the purpose, the gateway network stack is equipped with both IPv4 and IPv6 stack and facilitates 6to4 tunneling to support an IPv6 packet delivery via IPv4 networks. In addition, the gateway uses the same adaptation layer as the sensor node as shown in Figure 2. Its objective is to compresses and decompresses the incoming and outgoing packets for transparent packet delivery.

The gateway helps the PAN coordinator node with limited resources manage the entire PAN in performing the second and third role. The coordinator is connected to the gateway with a serial cable to communicate each other so that it can request the gateway to handle many works on behalf of it. The gateway as a first device retrieving a network prefix in both cases of IPv6 networks and 6to4 tunneling shares the network prefix with the PAN coordinator and periodically advertises a network prefix and notify all the sensor nodes of its aliveness by using unicast messages. Likewise, maintaining all information of sensor nodes in the gateway makes it much easier to cope with network management works. For instance, development of network management applications and tools is far more convenient than retrieving node information from the PAN coordinator and information residing in the gateway is useful for numerous applications such as commissioning, neighbor discovery, time synchronization, SNMP, security, and other research subjects.

b. Hardware

The developed IP-WSN gateway hardware is shown in Figure 4. The gateway hardware includes Embedded Intel Pentium processor, 512MB RAM, and 8GB CF memory to run Fedora core 7 and two USB ports for a serial communication between the gateway and the PAN coordinator and WLAN interface. The PAN coordinator is stacked on the gateway board to reduce volume.

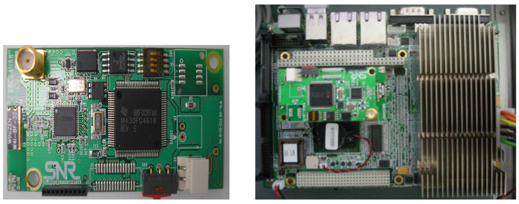

FIGURE 4. IP-WSN SENSOR NODE AND GATEWAY HARDWARE

IV. EVALUATION

The IP-WSN test bed has been built in the KOREN [5] which is a non-profit research network providing development environment for IPv6 research. To evaluate the feasibility of deployment both in IPv4/IPv6 networks, we located a remote test host in IPv4 networks outside the KOREN and IP-WSN in IPv6 networks of KOREN. 30 sensor nodes were deployed sparsely at intervals of more than 5 meters in the open area with no obstacles. The maximum number of children, which a parent can have in the HiLow routing protocol, was limited to two and

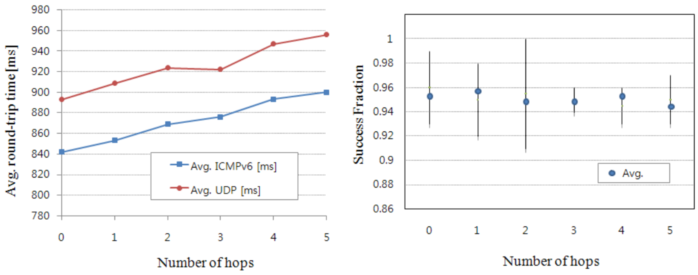

FIGURE 5. PERFORMANCE AND SUCCESS RATE

the depth to 5. The performance is measured by taking average round-trip time by hop of 100 ICMPv6 and UDP echo request/reply packets with which full test data is filled up to 127 bytes; i.e. the maximum frame size of IEEE 802.15.4.

As shown in Figure 5, the average round-trip time by hop for both ICMPv6 and UDP is getting slightly increased as the number of hops grows. The success ratio of packet delivery ranges from 91 % to 100% regardless of the number of hops. According to our analysis, two major factors affecting the average round-trip time were an asynchronized I/O operation to multiplex both serial and virtual tunneling interface inputs and the sum of transmission rate between the KOREN and a 6to4 relay server and between the remote host and the relay server. In addition, the only reason causing packet losses was the failure of serial communication between the gateway and the PAN coordinator independent of influence of wireless links.

V. CONCLUSION AND FUTURE WORK

In this paper, we introduced the architecture of smart highway integrating state-of-the-art technologies with IP-based wireless sensor networks and showed what we have implemented to build the infrastructure. The results shows approximately 95% of packets are successfully delivered via the Internet and encourage us to improve the performance by modifying a current I/O operation and the 6to4 tunneling method as well as the success ratio by fixing serial communication. Our future work will also include a new design of sensor node hardware with sufficient RAM, implementation of fragmentation/reassembly, low-power routing protocols, reliable security/mobility support, network management, and other research subjects to make IP-WSN play a crucial role in building the smart highway infrastructure.

REFERENCES

[1] TinyOS Community Forum, http://www.tinyos.net/.

[2] D. Kim, T. Sanchez Lopez, S. Yoo, J. Sung, "ANTS platform for Evolvable Wireless Sensor Networks ," to appear in LNCS, The 2005 IFIP International Conference on Embedded And Ubiquitous Computing (EUC'2005), Nagasaki, Japan, 6-9 December 2005.

[3] ZigBee Alliance, http://www.zigbee.org/.

[4] 6LoWPAN Working Group, http://tools.ietf.org/wg/6lowpan/.

[5] Korea Advanced Research Network, http://www.koren21.net/eng/about/overview.php.

[6] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks," RFC 4944, IETF Network Working Group, Sept. 2007.

[7] G. Mulligan and 6LoWPAN Working Group, "The 6LoWPAN Architecture," Proc. of the 4th workshop on Embedded networked sensors, pp. 78-82, Jun. 2007.