Design and Evaluation of In-vehicle Sensor Network for Web based Control

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Abstract

In the ubiquitous computing environment, it is expected that an intellectual vehicle with a capability of intelligence and communication has access to network and get useful information providing service. This requires a new network architecture and in-vehicle sensor network technology to support mobility of vehicle service. The mobility of vehicle service is to give users the vehicle services at any time and any where.

In this paper, CDMA-based network architecture is designed for intelligent vehicle services of remote vehicle diagnosis and management. The intelligent vehicle is equipped with a vehicle gateway and in-vehicle sensor network. The performance of the proposed network structure in terms of the round trip time taken to get a vehicle service is evaluated. The experimental results show that the round trip time is appeared to be different when a vehicle is driven or not and where it is driven. It is 776ms when a vehicle is stopped, 707ms when a vehicle is driven in the rural area, and 910ms in the urban area.

1. Introduction

In the ubiquitous computing environment, the intellectual vehicle will play a role as a sensor node with autonomous computation and communication capability in the network space. The intelligent vehicle system is one of the important Intelligent Transportation System (ITS) technologies because it provides people on walking, driving or at home with the advanced information services through the converging technologies of mechanics, electronics, computer and communication engineering. Specifically, the remote vehicle diagnosis and management is one of the services provided by the intelligent vehicle system in the near future.

The existing remote vehicle control systems have very short communication range and do not support the connection with the external network such as Internet either. Therefore, it puts limitation on the extension of vehicle services especially for the mobility. Besides, it is vulnerable to security attacks due to local area wireless communication. Most researches on web-based remote control system focus on the system at fixed place, and thus, do not consider the service mobility [1-3]. Therefore, a wireless remote diagnosis and management for vehicles is required with considering the vehicle's mobile environment.

In this paper, an intelligent vehicle system is designed to remotely diagnose and manage vehicles based on Code Division Multiple Access (CDMA) communication allowing drivers to have access to the network in driving vehicle. It has an in-vehicle sensor network for collecting and controlling vehicle status, a vehicle gateway for connecting the external network, and web-based remote server for offering remote vehicle diagnosis and management. Its performance is evaluated in terms of round trip time when a vehicle is driven at the rural and urban area.

This paper is organized as follows. Section 2 introduces the related work such as web-based remote diagnosis and management. The intelligent vehicle system for web-based remote vehicle diagnosis and management is explained in section 3. The design and implementation of the proposed system is described in section 4 and the performance evaluation is presented and analyzed in section 5. Section 6 concludes remark and future work.

2. Relate work

2.1 Remote control

Web-based Remote Diagnosis and Management (RD&M) system is one of the Man-Machine Interface

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(MMI) technologies that controls and diagnoses a target system in a remote place using standard web browser based on World Wide Web technology. The advantage of web-based control system is that a target system can be controlled via web browser irrespective of client's computing platform, only if it is connected to the Internet. Moreover, the client system does not need additional software installation to get an access to the RD&M system interface.

Researches on the existing vehicle RD&M system have been mainly focused on the local area wireless communication [4-6]. However, their control methods do not consider the security, extension, and mobility of services. The existing web-based RD&M is only for the target system at fixed place and thus unsuitable for vehicles because it does not consider the mobility of target system [7-11]. The researches on the vehicle RD&M system consider only unidirectional data transfer from the vehicle to the vehicle diagnosis services [12-14].

For the vehicle RD&M, the following issues should be addressed. First, it should support bidirectional communication for human to make an interaction with vehicle remotely. Second, mobility and security service should be guaranteed. In order to make them possible, intelligent vehicle terminal along with web-based RD&M system is needed.

2.2 Service mobility

The RD&M system for vehicle consists of a sensor node for vehicle status detection, an actuator for vehicle control, and a communication module.

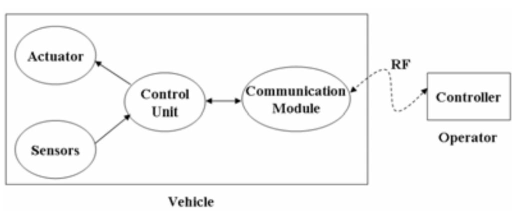

Figure 1. Scheme for remote vehicle control

Reflecting on vehicle's mobile environment that allows drivers to connect to the Internet at their convenience, a communication technology for seamless and wireless interactive connection to the network is strongly demanded. However, current wireless network protocol like the Wireless Local Area Network (WLAN) permits mobile devices to be connected to the internet within a limited area and does not support handoff between wireless access points. It can be said that the wireless packet data communication is more effective on the cellular wireless network for the mobility intensive vehicle environment because it is far more generous in the limit of communication. However, a vehicle terminal system does not allow an external network to get a connection because it can not be assigned to its unique IP address [15-17].

No matter where users are, an RD&M system makes them get interactive service for remote vehicle diagnosis and management. A server-client network model, called vehicle-oriented server-client model as shown in Fig. 2, can be a solution for interactive services in vehicle's mobile environment. Inter networking Function (IWF) has a role of protocol conversion between wireless network and TCP/IP network.

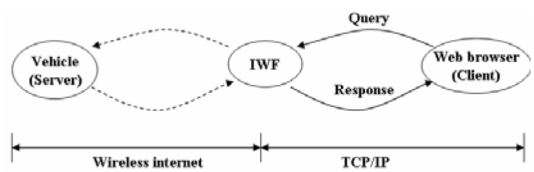

Figure 2. Vehicle-oriented server-client network model

It requires a large scale and high performance vehicle server to be installed in a vehicle. Besides, high speed wireless network infrastructure and wireless network protocol such as IPv6-based mobile IP are needed because the car server should always be connected to the Internet. Current IPv4 based internet protocol is too restrictive to guarantee this kind of dynamic connection to the Internet.

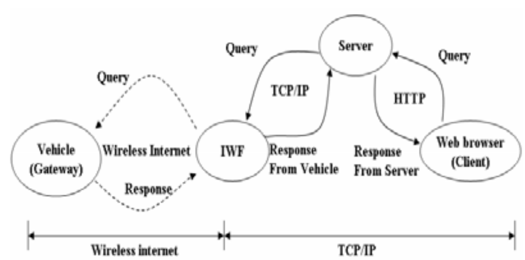

Figure 3. Network-oriented server-client model

For another solution, Fig. 3 shows a network-oriented server-client model, where a server is separated from the vehicle. This network model can support the mobile services of vehicles because it allows a vehicle driver to have access to the Internet via cellular wireless network. In addition, a driver can get remote diagnosis and management services by using TCP/IP web browser at any time and any where.

The network-oriented server-client model makes both vehicle drivers and web users get interactive RD&M services in the mobile environment. Moreover, it can easily connect the control server with other networks allowing multiple users to get the RD&M services. The security attack is almost impossible because packet data communication is based on the cellular wireless network such as CDMA or GSM, which is more intensive in a security and guarantees stable connection at the speed of 250km/h.

3. Design of web-based vehicle control system

3.1 In-vehicle sensor network

Figure 4 shows a concept of intelligent vehicles in the ubiquitous network space.

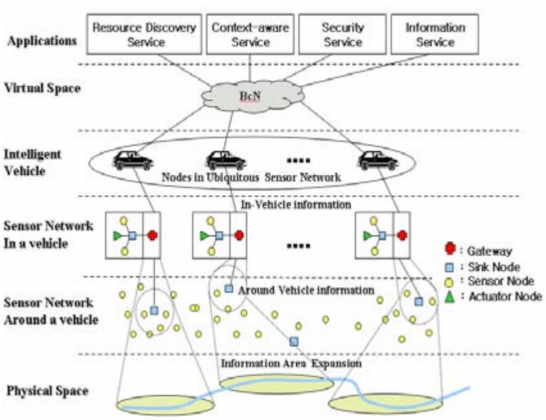

Figure 4. Intelligent vehicle in the ubiquitous network

The wire and wireless sensor network has a role of gathering the vehicle status data and controlling the actuators. The vehicle gateway allows a vehicle to have access to the external huge heterogeneous network so that the vehicle does not only offer vehicle status information to remote users but also receives vehicle control messages from the external network. Besides, the scope of the sensor node's information collection is not limited to the vehicle itself but extended to the area around the vehicle, deploying the wireless sensor nodes on the road.

Fig. 5 shows the structure of the intelligent vehicle information system proposed in this paper. The

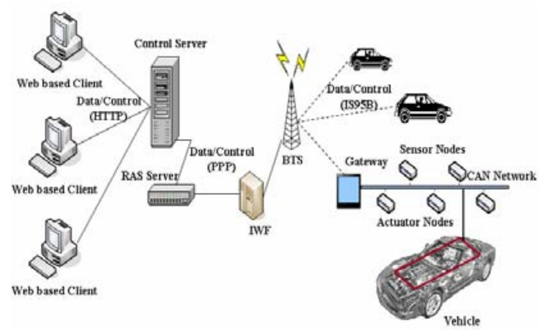

Figure 5. Intelligent vehicle system structure

intelligent vehicle information system consists of the sensor nodes, actuator nodes and the vehicle gateway in a vehicle, which is connected to Controller Area Network (CAN). Besides, the vehicle gateway is connected to the Internet via CDMA mobile communication network. The gateway has a role of collecting vehicle status data from in-vehicle sensor network and converting network protocol to connect the in-vehicle network with the external network.

3.2 Control server

The control server is the core unit to offer the web-based remote vehicle diagnosis and management service to out-vehicle web clients as well as in-vehicle drivers. The structure of the control server as shown in Fig. 6 consists of a web server, security manager, a server-gateway communication manager, a language converter, a core engine and data-base.

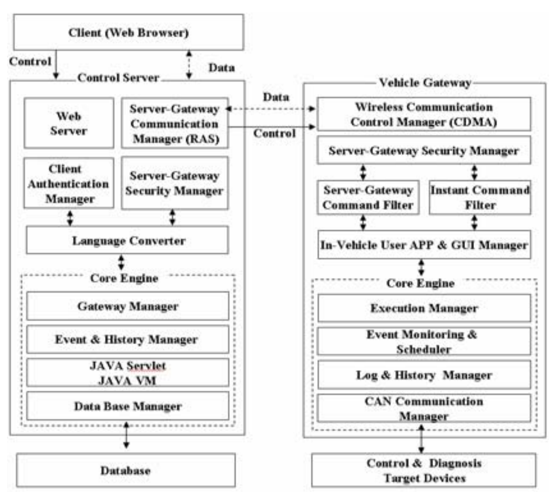

Figure 6. Software architecture for control server and vehicle gateway

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The web server provides a web client with a web-based interface. The server-gateway communication manager is in charge of secure connection and access control between the control server and the vehicle gateway. The security manager consists of a client authentication manager for web clients and the server-gateway security manager for drivers. The language converter to exchange information among the different types of networks has a role of converting the HTTP protocol packet format on the web client side into PPP format on the vehicle gateway side and vice versa. The core engine consists of a gateway manager, an event and history manager and a database manager. The gateway manager is in charge of managing the connection request, the gateway configuration and the information transmission and reception. Finally, the event and history manager has a role of an event analysis, a control command transmission and execution, a reception data analysis and a log file generation.

3.3 Vehicle gateway in the in-vehicle sensor network

The main role of vehicle gateway is to translate and execute control commands received from the control server. It cooperates with the in-vehicle sensor network to help the remote vehicle diagnosis and management performed. It also provides in-vehicle drivers with useful information that is sent from the control server. As shown in Fig. 6, the vehicle gateway consists of a wireless communication manager, a server-gateway security manager, a command filter, core engine and other application programs for in-vehicle drivers.

The wireless communication manager controls a connection request and a wireless packet data communication between the control server and the vehicle gateway. The cellular network for wireless packet data communication such as CDMA and GSM does not support direct connection from the control server to the vehicle gateway. In order to resolve this problem, the cut and call back connection mechanism is proposed to ensure the connection from the control server to the gateway.

Fig. 7 shows the cut and call back protocol proposed in this paper. Generally, the existing mobile data communication network such as CDMA does not support two-way network connection in the mobile environment. For the two-way network connection, the cut and call back mechanism requires the caller identification service. If the control server requests a connection to the vehicle gateway, the vehicle gateway

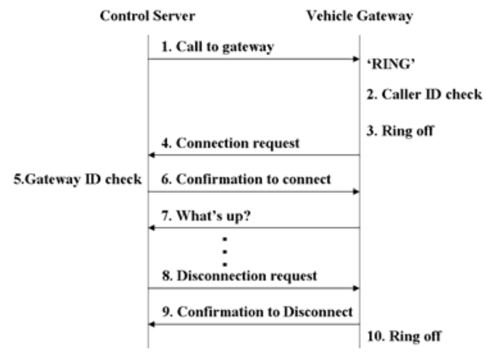

Figure 7. Cut and Call Back protocol

will identify the caller identification of the control server. The server-gateway security manager confirms the authentication as soon as a connection request is received from the control server. The command filter, which consists of a server-gateway command filter and an instance command filter, analyzes the control commands from the control server or a mobile phone and then gives back the execution results of the commands. The core engine includes an execution manager, an event monitor and scheduler, a log and history manager and CAN communication manager. The execution manager diagnoses and manages a vehicle in response to the control commands. The event monitor and scheduler detects events collected from the in-vehicle sensor network and sends control messages to handle actuators via in-vehicle sensor network. The log and history manager is in charge of a log file generation. The log file has various profiling data collected in the vehicle gateway. The CAN communication manager offers an access interface to the in-vehicle sensor network.

3.4 Sensor node

In general, the sensor nodes are hardly collected and recharged for recycle after they are deployed in the sensor filed. Therefore, the power consumption is one of the very significant constraints in the sensor node. However, the sensor nodes deployed in the vehicle have more important issue than the power consumption. It is how to tolerate electromagnetic noises prevalent in the vehicle. In this paper, we've chosen the CAN network for the in-vehicle sensor network because it can tolerate in-vehicle noises and supports high speed data rate up to 1Mbps.

The node structure for the CAN based in-vehicle sensor network is shown in Fig. 8. It consists of a CAN

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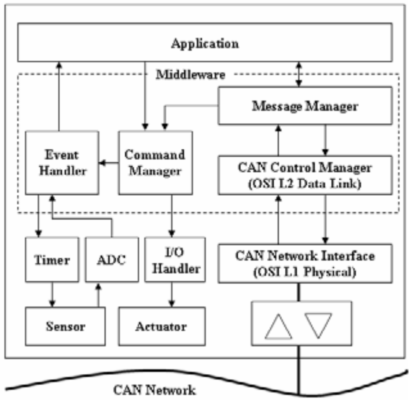

Figure 8. Sensor node architecture for in-vehicle sensor network

protocol processing module, a message processor, a sensor and actuator management module.

4. Implementation of web-based vehicle sensor network

4.1 In-vehicle sensor network and vehicle gateway

Fig. 9 shows the system platform for the web based vehicle control proposed in this paper. The implemented system consists of a web client, a control server and a vehicle gateway. The control server is based on the JAVA platform to support web based remote vehicle diagnosis and management. The in-vehicle gateway is implemented with embedded system with PXA 255 processor, which has a 32-bit ARM core developed by the Intel. It runs on the embedded Linux. The hardware components of the gateway consist of a processor, a CAN communication interface, GPS receiver, a CDMA modem and LCD display device.

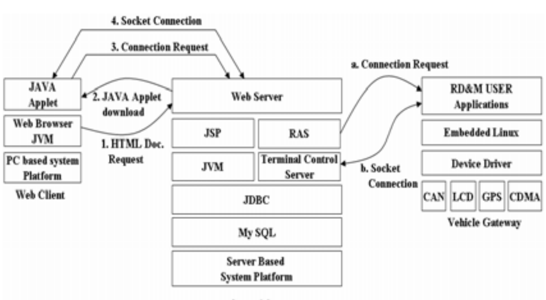

Figure 9. Web-based vehicle control system platform

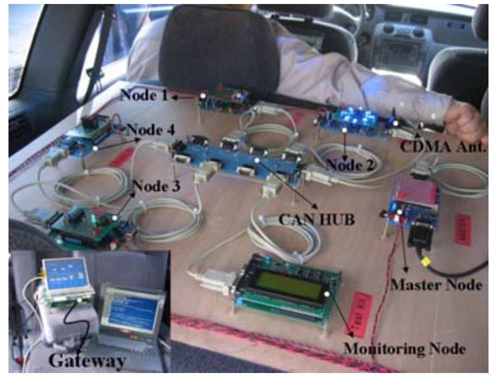

Figure 10. Vehicle gateway and In-vehicle sensor network system

Fig. 10 shows the implemented vehicle gateway and in-vehicle sensor network, which are installed in a vehicle for experiments. The sensor nodes are connected to the in-vehicle sensor network. They consist of temperature node, humidity node, inclination node (2 axes) of vehicle, battery and atmospheric pressure node. The actuator nodes such as horn, head lamp, door and digital radio are installed in the in-vehicle sensor network. The in-vehicle sensor network using CAN network protocol is based on the master-slave communication model. The vehicle gateway acts as a master.

4.2 Remote diagnosis and management

The vehicle diagnosis and management services for web clients and in-vehicle drivers are developed. Fig. 11 shows a capture of user interface for in-vehicle diagnosis and control services. Using these services, the in-vehicle drivers can monitor a vehicle status and control actuator.

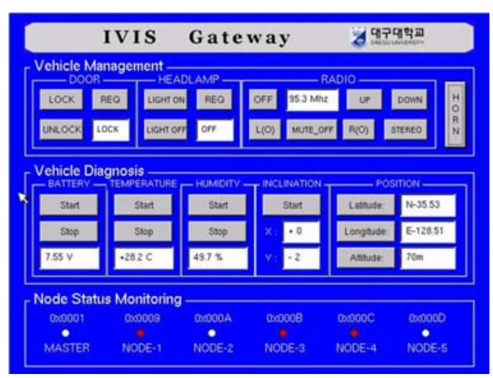

Figure 11. User interface for vehicle management, diagnosis and vehicle gateway control

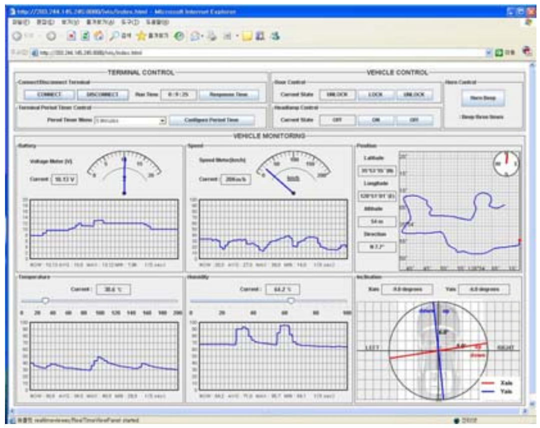

Figure 12. User interface for Web based Remote Vehicle Diagnosis and Management

The web based remote services is shown in Fig. 12, which is used for web clients. A web client can diagnose and control a vehicle remotely through the control server, the vehicle gateway and in-vehicle sensor network. It is provided with remote status information such as position, speed, altitude, temperature, battery state and inclination of the intelligent vehicle. The web based remote services also support the control of actuators such as door, head lamp, horn and digital radio in vehicle at distance place.

5. Performance evaluation

5.1 Round trip time

For performance evaluation, the web based vehicle control system can be modeled as shown in Fig. 13. The round trip time is defined as time taken for a web client to receive a response from a sensor node in the sensor network since its request.

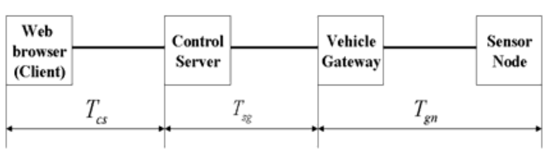

Figure 13. Performance analysis model

Where T_{cs} is communication latency between a web client and control server when web client request a service, T_{sg} is the latency time between the control server and the vehicle gateway, and T_{gn} is the time between the vehicle gateway and a sensor node in the in-vehicle sensor network. Therefore, T_{rtt}, which is a round trip time between a web client and a sensor node, can be defined as follows:

$$\begin{aligned} &T_{rtt} = T_{cs} + T_{sg} + T_{gn}, \\ &T_{cs} = \mathit{Client\ to\ server\ response\ time} \\ &T_{sg} = \mathit{Server\ to\ gateway\ response\ time} \\ &T_{gn} = \mathit{Gateway\ to\ sensor\ node\ respone\ time} \end{aligned} \quad (1)$$

The communication latency between web client and control server is depended on the amount of transmission data and network load in the web client side. Therefore, it is almost impossible to determine the exact value of the T_{cs}. The main factors of the communication latency T_{cs} are the processing time, the downloading time for HTML documents and JAVA applets, and the propagation delay between the web client and the control server. T_{cs} is given as follows:

$$\begin{aligned} &T_{cs} = \tau_{cproc} + \tau_{javadown} + \tau_{csdealy}, \\ &\tau_{cproc} = \mathit{Client\ processing\ time} \\ &\tau_{javadown} = \mathit{Java\ applet\ download\ time} \\ &\tau_{csdealy} = \mathit{Client\ to\ server\ propagation\ delay} \end{aligned} \quad (2)$$

The communication latency between the control server and the vehicle gateway includes the performance factors such as execution latency of the control server and the network traffic, which is difficult to estimate. T_{sg} can be defined as the sum of the data processing time of the control server, the initial connection time between the control server and the vehicle gateway, and the propagation delay of the wireless network. Therefore, T_{sg} is given as follows:

$$\begin{aligned} &T_{sg} = \tau_{sproc} + \tau_{cutback} + \tau_{sgdelay}, \\ &\tau_{sproc} = \mathit{Server\ processing\ time} \\ &\tau_{cutback} = \mathit{Cut\ and\ call\ back\ delay} \\ &\tau_{sgdelay} = \mathit{Air\ space\ data\ propagation\ delay} \end{aligned} \quad (3)$$

T_{gn} is the communication latency between the vehicle gateway and a sensor node in the in-vehicle sensor network and given as (4). In the equation (4), P_d is a delay time taken to process data frames at the vehicle gateway. R_m is the worst-case latency time taken for a sensor node to transfer data frames to the vehicle gateway via CAN network.

$$T_{gn} = P_d + R_m \quad (4)$$

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Let τ_{scan} be the delay time taken for a sensor node connected to the CAN network to process a data frame containing a control message that is fetched from a CAN stack. Let τ_{debo} be the time taken for a sensor node to take stable data from a sensor and τ_{nproc} be the time taken to push a sensor data to a CAN stack since processing the sensor data. Then, P_d can be defined as follows:

$$
\begin{aligned}
&P_d = \tau_{scan} + \tau_{debo} + \tau_{nproc}, \\
&\tau_{scan} = Input - scan\ cycle\ time \\
&\tau_{debo} = Input\ filter\ /\ Debounce\ time \\
&\tau_{nproc} = Software\ processing\ time
\end{aligned}
\tag{5}
$$

R_m is the worst-case latency time taken to load the sensor data on the CAN network since storing the sensor data into the CAN stack. It is, in turn, defined as the equation (6), where q_m is a worst-case queuing time and *Cm* is the maximum transmission time for a transmission data. Therefore, R_m is defined as follows:

$$R_m = q_m + C_m \tag{6}$$

q_m shown in equation (7) is the sum of the block time B_m, which is the delay time by other lower priority transmission frames than the given priority m frame, and the waiting time by the higher priority frames [18-20]. J_j is a jitter time taken for a given frame to be stored in queue, τ_{bit} is at time to transmit one bit of the frame data to the CAN network, T_j is a generation period of higher priority frames than the give frame m, and the C_j is the worst-case computation time of the frame.

$$q_m = B_m + \sum_{\forall \in hp(m)} \left\lceil \frac{q_m + J_j + \tau_{bit}}{T_j} \right\rceil C_j \tag{7}$$

$$
\begin{aligned}
&B_m = Blocking\ time\ of\ lower\ priority\ message \\
&hp(m) = Set\ of\ higher\ priority\ messages\ than \\
&\qquad message\ m \\
&q_m = Queuing\ delay\ of\ hp(m) \\
&J_j = Jitter\ of\ given\ task\ J \\
&\tau_{bit} = Bit\ time \\
&T_j = Period\ of\ given\ task\ J \\
&C_j = Worst - case\ computation\ time\ of\ given \\
&\qquad task\ J
\end{aligned}
$$

The maximum transmission latency, C_m, for a transmission frame to be completely loaded on the CAN network is the sum of the stuff bit time, overhead bit time and transmission data bit time as shown in equation (8). The transmission frame consists of data field up to 8 bytes including 47 bits for overhead and stuff bit. In order to prevent errors, the stuff bit is added to the frame when same bits are transmitted in 5 bit series. Therefore, C_m can be defined with S_m, which is the length of data field in the transmission frame, overhead bit (47 bits), and bit time τ_{bit} due to the addition of extra frame bits. The extra frame bits are calculated from dividing the overhead bits and 34 bits, which is affected by the extra frame bits, by its pattern length.

$$C_m = \left(\left\lceil \frac{34 + 8S_m}{5} \right\rceil + 47 + 8S_m \right) \tau_{bit} \tag{8}$$

5.2 Experimental results

In this paper, a CDMA modem with IS-95B up to 64 Kbps is used to communicate between the control server and the vehicle gateway. Table 1. shows the experimental results for T_{sg}. It is measured with the latency time taken to make a complete connection between the control server and the vehicle gateway. the result shows that the average communication latency, When the control server requests a connection to the vehicle gateway using the cut and call back protocol, is 10.302 sec and the standard deviation is 0.821 ms.

Table 1. Connection time

Init.	Connection delay (sec)			
	Min.	**Ave.**	**Max.**	**Std.-Dev.**
Server	8.76	10.302	12.123	0.821
Gateway	4.064	5.608	7.905	1.131

On the other hand, connecting the gateway to the control server does not use the cut and call back protocol and thus reduces the communication latency by about 50%. The results show that the average communication latency is 5.608 sec and the standard deviation is 1.131 sec. The delay time due to the cut and call back protocol includes time to identify a caller's identification and make a call back to the control server.

Fig. 14 shows the results of T_{gn} that is the communication latency between the gateway and the sensor node based on the master-slave communication model. In this experiment, the bit rate of CAN network is up to 1Mbps and all the transmission data has a fixed priority. Three sensor nodes are connected to the CAN network. Every sensor nodes transfer their data to the vehicle gateway in charge of master node at every one second. The master node has the highest priority and each slave node has its own priority in order. Assuming the size of the transmission message to be 8 bytes, C_m is 135.5 μsec, which is all the same for every sensor nodes.

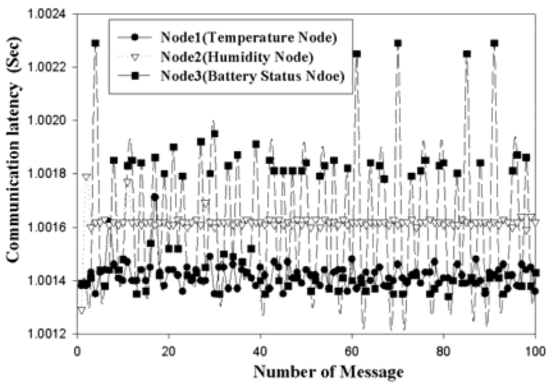
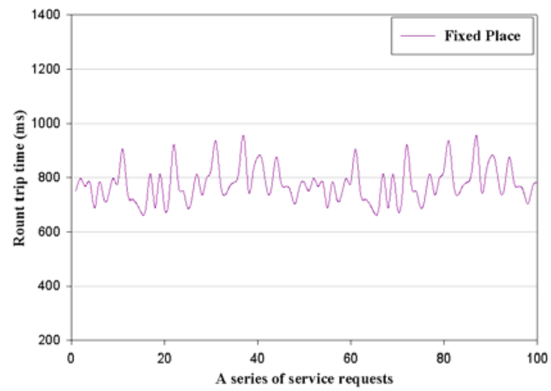


Figure 14. Communication latency between vehicle gateway and sensor nodes

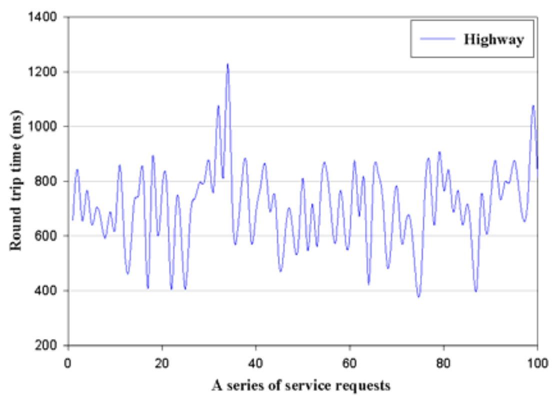
As shown in Fig. 14, the average communication latency between sensor nodes and the vehicle gateway is 6.669 ms. The slave node 1 with temperature sensor has the lowest communication latency among sensor nodes because its highest priority results in the shortest waiting time. The slave node 3 with battery sensor is the longest in the latency and the largest in the range of fluctuation. It is because it has the lowest priority and the longest waiting and delay time P_d defined in the equation (5) and (7).

The communication latency for the web based remote vehicle diagnosis and management is also analyzed in the mobile environment. The communication time is measured at fixed place, highway around rural area and downtown. The vehicle gateway and the in-vehicle sensor network are installed in the testing vehicle going through the experimental areas. The round trip time T_{rtt} between a web client and sensor nodes are measured.

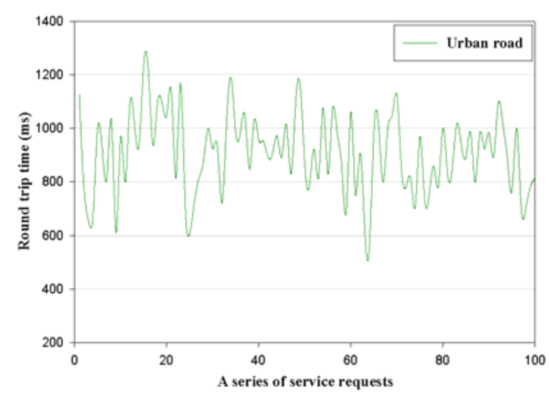
The experimental results show that the average T_{rtt} at the fixed place amounts 776.44 ms and the standard deviation is 65.72 ms as shown in Fig. 15 (a). Fig. 15 (b) shows the round trip time when the testing vehicle goes through the highway around rural area with the speed above 100 km/h. The average T_{rtt} at the rural area is 707.34 ms and the deviation is 146ms. Fig. 15 (c) shows the results of T_{rtt} at the urban area. When the testing vehicle goes through the downtown at the speed of 30 km/h, the average T_{rtt} is 910.52ms and the standard deviation is 147ms.



(a) T_{rtt} at fixed place



(b) T_{rtt} at rural area



(b) T_{rtt} at urban area

Figure 15. Round trip time between web client and sensor nodes

As shown in Fig. 15, the round trip time at the fixed place is shorter and more stable than others because it does not have the handover delay time for cellular network and only depends on the mobile communication network traffic in that area. On the other hand, the experimental results at the rural and urban area are seriously fluctuated because of the frequent handover of the CDMA. Specifically, the round trip time at the urban area is longer and more fluctuated than other areas. It is because there are busy network traffic and frequent handover with pico cells about 200m of radius.

6. Conclusion

The present remote vehicle control system with short range wire and wireless communication is restricted to provide with various services and access to external heterogeneous network. Moreover, it does not support service mobility for vehicles. The existing web-based remote diagnosis and management system is only for the target system at fixed place. It is unsuitable for vehicles because it does not consider the mobility of target system.

In this paper, we present the vehicle information system and the network architecture for the intelligent vehicle in the ubiquitous computing environment. The proposed intelligent vehicle system allows in-vehicle drivers and web clients to have an access to the vehicle at any time and any where. In addition, it provides a remote vehicle diagnosis and control on the Internet. Specifically, if a web browser is available, the web clients can diagnose and manage the vehicles remotely at any time and any where in the web-based remote vehicle diagnosis and management system. Moreover, residing in the Internet and separated from the vehicle, the control server can be easily connected to the several other networks and provides several types of services. The web based remote vehicle diagnosis and management system uses CDMA based cellular mobile network to support service mobility for vehicles.

We design and implement the vehicle gateway, the in-vehicle sensor network system and the control server to offer web based remote vehicle services. The cut and call back protocol proposed in this paper guarantees bidirectional connection between the control server and the vehicle gateway.

The performance evaluation of the web based remote control system is performed at various environments. The experimental results show that the average round trip time amounts to 766ms at fixed place, 707ms at rural are and 910 ms at urban are. It is expected that the intelligent vehicle sensor network system will be used for an ambulance's emergence services, vehicle's history management services and vehicle relationship management services.

Acknowledgement

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