A Study on Wireless Vehicular Control Network (WVCN): Architecture, Protocol and Failure Tolerance

The University of Michigan-Dearborn
Henry W. Patton Center for Engineering
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A Study on Wireless Vehicular Control Network (WVCN): Architecture, Protocol and Failure Tolerance

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Synopsis

Automobile developers rely increasingly on adopting more and more microprocessors and electrical devices to achieve enhanced capabilities, resulting in excessive amounts of cabling. The ever-growing cabling leads to significant difficulties in the design, manufacturing, installation, and maintenance associated with wired components. The sheer cost, weight, and space claims of wiring force trade-offs against the capabilities a vehicle could offer. This crucial situation motivates the development of wireless networked control systems (NCS), which inherently eliminate the concerns of cabling in automobiles. Wireless NCS will surely provide attractive benefits for automobile manufacturers. At first, there will be a dramatic reduction in materials and labor in manufacturing. Wireless NCS will feature a flexible and scalable design for various vehicle modes and decrease wiring-related problems. Finally, the pervasive wireless propagation could be leveraged to realize dynamic network reconfiguration and many new features.

In the period of 2007-2008, we have performed the planned research activities and conducted intensive experiments for vehicular ultra wideband (UWB) channel modeling. Seven journal papers published in IEEE Transactions and Magazines, and four conference papers were presented at IEEE international conferences. In the meantime, seven drafts have been revised or submitted for publication. The wireless access in vehicular environments (WAVE) prototype was demonstrated at *IEEE TridentCom* 2007, Orlando. A disclosure titled *Enhanced carrier frequency offset/Doppler shift estimator for WAVE systems* was released to the Tech Transfer office of the University of Michigan in June 2007.

We plan to complete more than ten journal and conference papers and more than six external proposals in the period of 2007-2008.

1. Background

Developers of a board range of embedded systems rely increasingly on computers and electronics as enablers for new capabilities and improved performance. For example, in the automotive sector, competition and regulatory pressure has motivated the development of x-by-wire control systems. These systems replace conventional mechanical-hydraulic systems with computer-controlled electric motors for steering, throttle control, transmission control, etc. The desire to improve safety has lead to the emergence of systems for collision warning and avoidance, traction control, and skid recovery. Competition between manufacturers has lead to sophisticated entertainment and information systems. It is certain that this trend will continue for the foreseeable future. An important consequence of this trend is an excessive amount of cabling found in automotive systems. For example, certain Lexus models have 4 km of wiring. This amount of cabling presents developers of automobiles with significant challenges. Among these are:

- The sheer weight and space claim of the cabling will force trade-offs against what capabilities can be offered in a given automobile model.
- The cost of the cabling alone becomes very significant when considering that worldwide automobile production is over 55 million units annually.
- The switches and connectors associated with assembling an automobile wiring harness can have costs ranging in the neighborhood of $50−$100 per automobile.
- The design of a wiring harness is time consuming and inflexible, taking several engineer years to design.
- Installation of cabling is a tedious and labor intensive process that adds to manufacturing costs. Mistakes during installation can lead to costly and difficult maintenance issues.
- Manufacturing large amounts of cabling makes them prone to manufacturing defects that are difficult to detect and may not surface until many units are in use.

The central issue that we observe is that the reliance on conventional wiring to enable new capabilities and improve performance has created its own problem. This problem will grow unless an effective alternative approach is found: wireless networked control systems (wireless NCS).

2. Objectives

The chief objective of this effort is to reduce or eliminate many of the concerns associated with the design, manufacturing, and maintenance of conventional wiring harnesses, thus enabling the continued performance enhancement and capability expansion of automotive systems.

The objectives of this efforts include:

1) ultra wideband (UWB) channel modeling within vehicles;
2) orthogonality frequency-division multiplexing (OFDM) performance studies;
3) bit error rate (BER) versus signal to noise ratio (SNR) performance studies for UWB radios within vehicles; and
4) dynamic medium access control (MAC) protocol design for wireless NCS.

3. Approach

The approach applied balances theoretical study and experiment. At first, the system performance will be mathematically derived and simulated based on a system model described in Matlab languages.

UWB channel modeling within vehicles has been extensively measured, upon which a vehicular UWB channel model is presented. The model provides a reliable foundation for the performance analysis and system design for wireless NCS.

4. Results

Seven journal papers were published in IEEE Transactions and Magazines discussing the power average to peak ratio (PAPR), brake-by-wire systems, and MAC protocols [27-28, 31-35]. Four conference papers were presented at IEEE international conferences [29-31, 39]. Seven drafts have been revised or submitted for publication [26, 36-38, 40-42]. Two external proposals have been submitted, which are listed below:

1. NSF Theoretical Foundations, "Theoretical Study on Inter-Vehicle and Intra-Vehicle Communications and Control Systems: Channel modeling, Performance Analysis and Protocol Design," $150,029 (pending) PI.
2. NSF Course, Curriculum, and Laboratory Improvement, “Wireless access in Vehicular Environments Laboratory for Undergraduates,” $149,936 (pending) PI.

In addition,

- The wireless access in vehicular environments (WAVE) prototype was demonstrated at IEEE TridentCom 2007, Orlando, May, 2007.
- A disclosure titled enhanced carrier frequency offset/Doppler shift estimator for WAVE systems was released to the Tech Transfer office of University of Michigan in June, 2007
- In preparation for submitting a book proposal with a title of Mobile and Vehicular Communications System and Technology to the Artech House.

Finally, we plan to complete more than ten journal and conference papers and more than six external proposals in the period of 2007-2008.

5. Conclusions

We have realized that there are a wide range of applications for wireless NCS, such as manufacturing plants, vehicles, and aircrafts. Wireless NCS allows for reduced system wiring, increased system agility, and simplified system diagnosis and maintenance. In 2007-2008, we will continue the study on channel characteristics, robust information delivery schemes, system stability, and fault tolerance design for wireless NCS with this support.

Through intensive publications in top journals and at international conferences, we are making our research work well recognized in this promising area. In the meantime, we are actively seeking cooperation opportunities with the local automobile industry to commercialize our research results.

6. Impact

Educational:

Mr. Walid Aldeeb, a graduate student, has worked on the channel characteristics and performance analysis of UWB radio applied in vehicles. His research work was presented at IEEE Sarnoff 2007, and he is currently working on a draft that will be submitted to *IEEE Transactions on Vehicular Technology* by the end of this year.

The background and technical merits of wireless NCS have been introduced in the courses ECE 471 Data Communications and Computer Networks, ECE 570 Computer Networks, and ECE 550 Communication Theory, all offered by the Department of Electrical and Computer Engineering at the University of Michigan-Dearborn.

In ECE 550, two projects are deliberately designed to allow students to study and simulate the performances of UWB radio using pulse position (PPM) modulation and binary phase shift keying (BPSK) modulation. 25 graduate students took the course in the winter of 2007.

A new course dedicated to WAVE has been proposed and submitted for NSF CCLI 2007. This curriculum will focus on teaching the principles and technologies of WAVE systems at the Electrical and Computer Engineering (ECE) Department of University of Michigan-Dearborn (UMD). The proposal requests $149,936 from NSF to establish a laboratory consisting of five WAVE testbeds, which will allow students to learn the advanced technologies applied to WAVE systems by carrying out carefully designed tasks.

This new course, if granted, will be offered starting from the fall of 2008. The estimated number of students is about 30.

Industrial:

The elimination of a significant portion of wiring and the associated switches and connectors will provide significant benefits for the automotive industry. One benefit is that there will be a significant reduction in material costs associated with manufacturing an automobile. This will also lead to significant reduction in labor costs during manufacturing and decrease the likelihood of manufacturing or installation problems related to cabling. A wireless design will also be more readily useable across different platforms, thereby reducing design costs. Furthermore, the pervasive nature of the wireless channel could be leveraged to realize dynamic reconfiguration and new capabilities. These advantages will facilitate continued performance advances and growth in capabilities for automotive systems. Besides automotive applications, an increased reliance on computer and electronic components to improve performance and provide new capabilities can be observed in a wide range of complex control systems (e.g. aerospace, defense, and manufacturing). Thus, it can be easily envisioned that excessive cabling and associated concerns will become an important issue in many other challenging scenarios. Aerospace systems have extremely tight reliability requirements and are especially sensitive to weight and space claim issues. Ship borne control systems will have to contend with longer distances and watertight compartments that act as reverberation chambers. Defense systems have stringent reliability requirements and must operate in hostile electromagnetic interference environments. Thus, while this

effort specifically targets automotive control systems, we also view this work as laying the foundation for wireless NCS in a wide range of applications.

7. Acknowledgments

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