Paper No. 993183
An ASAE Meeting Presentation
UILU-ENG-99-7031

Wireless Networking for Control and Automation of Off-road Equipment

by

J. D. Will
Research Assistant
Agricultural Engineering
University of Illinois at Urbana-Champaign
Urbana, IL

D. D. Moore
Research Programmer
National Center for Supercomputing Applications
University of Illinois at Urbana-Champaign
Urbana, IL

E. N. Viall
Research Assistant
Agricultural Engineering
University of Illinois at Urbana-Champaign
Urbana, IL

J. F. Reid
Professor
Agricultural Engineering
University of Illinois at Urbana-Champaign
Urbana, IL

Q. Zhang
Assistant Professor
Agricultural Engineering
University of Illinois at Urbana-Champaign
Urbana, IL

Written for Presentation at the
1999 ASAE Annual International Meeting
Sponsored by ASAE

Sheraton Centre Hotel, Toronto Canada
July 18 – 21, 1999

Summary:

This paper describes new wireless networking technology and its applications to off-road equipment. We present an overview of current wireless networking equipment as well as a description of a commercially available voice recognition package. We then demonstrate several examples of the use of wireless networking for control and automation on an agricultural platform. These examples include telecasting of vehicle information, control in a virtual environment, web-based steering control, and remote voice-based steering control. We conclude by listing several possibilities and extensions for this work.

Keywords:
Vehicle Guidance, Wireless Networking, Voice Recognition, Automation, Virtual Control

ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA
Voice: 616.429.0300 FAX: 616.429.3852 E-Mail: <hq@asae.org>

Introduction

Off-road equipment such as road graders, agricultural tractors, and mining vehicles are becoming increasingly computerized and automated [13]. Local control networks are increasingly common in cars, trucks, and equipment and are increasing in implementation [4, 12, 13]. At the same time, the number of sensors and actuators on the vehicles are also increasing [6, 12]. In agricultural applications, the amount of information and data needed and collected during harvesting operations is growing exponentially. The need to process this information, as well as the need to observe or control the vehicle itself lend well for the solutions that connectivity and networking provide.

Several products have recently come on the market to implement standard networking protocols over wireless channels [2, 8, 14]. These products have seen trends in decreasing price, increasing bandwidth, and increasing range [2, 14]. Present technology has come to such a point that these products are quite useful in off-highway equipment applications. We demonstrate several applications using these products in the control and automation of agricultural equipment.

The structure of this paper is as follows. We first give a review of present wireless networking technology and commercially available products. We then give some examples of software applications that can be used over networks, specifically voice recognition software and voice networking products. For our specific platform, we present examples of vehicle information telecasting in several media. We also show examples of vehicle steering control in web-based, voice-based, and virtual-based environments. Finally, we talk about expansion of the wireless technology and it’s applications for future work.

Wireless Networking Technology

Wireless Ethernet products have been available for several years [1, 10, 11], but only recently have they increased in range, decreased in cost, and improved in functionality such that they are usable for applications in off-highway control and automation. This paper will review two different commercially available wireless networking products here, the Baystack 600[1] series and the Lucent WaveLAN series.

Wireless local area networks (LAN), appeared in the market around 1990, but the concept for such products has been around since the late 1970's [8]. These products have developed over the years such that they have increased in data transfer rates and transmission range and are suitable for mobile applications in off-highway control and automation. When the FCC allowed unlicensed use of 3 frequency bands in the mid 1980's, significant interest in wireless LAN's developed. These three industrial, scientific, and medical (ISM) bands are at 902-928 MHz, 2.400 - 2.4835 GHz, and 5.725 - 5.850 GHz. Completion of the IEEE 802.11 standard in July 1997 makes use of the 2.4 GHz ISM band [8, 9, 10].

---

[1] Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the University of Illinois, and does not imply the approval of the named product to the exclusion of other products that may be suitable.

The IEEE 802.11 standard was implemented for wireless LAN's. Since essentially a LAN is used as the backbone for the wireless networking of off-road equipment presented in this paper, a brief overview of the IEEE 802.11 standard is given. The standard supports two types of topology for the wireless network relevant to this paper. One involves stations (computers) accessing a backbone network or an existing wired LAN through access points. The other involves stations communicating directly with each other in an independent network without an access point. Both topologies can be implemented for the application of wireless networking for off-road equipment. The fundamental building block of the IEEE 802.11 architecture is a basic service set (BSS). A BSS consists of all stations that can communicate with each other, such as a group of stations under one access point [5, 9].

Three different physical layer implementations are provided in the IEEE standard. These three include the 2.4 GHz ISM frequency hopping spread spectrum (FHSS), the 2.4 GHz ISM direct sequence spread spectrum (DSSS), and infrared (IR) light. Both commercially available wireless products reviewed in this paper employ the FHSS and DSSS physical layer, of which, we use products that employ the DSSS layer. FHSS systems vary the frequency at which data is transmitted among a set of frequencies. This frequency-hopping pattern is known by the receiver so that the receiver's frequency synthesizer can hop in synchronism and recover the original data signal [9]. Because of this frequency-hopping, FHSS systems are slower in terms of transmission rates as compared to DSSS systems. DSSS systems modulate the original data signal by a wideband spreading signal. The spreading signal is known by the receiver, and hence the original data signal can be recovered [5, 9]. The IEEE 802.11 standard also supports two different data rates (1 Mb/s and 2 Mb/s) for each of the physical layers.

The Baystack 600 series wireless products, manufactured by Nortel Networks, include FHSS and DSSS systems, provide full network functionality, and are IEEE 802.11 compliant. The access points' area can be overlapped to increase system capacity and stations can move freely between access points with uninterrupted communication. Baystack wireless networks can provide up to 10 Mb/s or more bandwidth for a given coverage area by overlapping access point coverage areas [2]. Software utilities allow for comprehensive installation and configuration and yield real-time information about network connections. Security is provided through access point locking, user authentication, data scrambling, domain identification, and Frequency Hopping [2].

Figure 1. Baystack 660 series wireless PC card (Netwave version shown).

There are two product lines within the Baystack 600 series wireless products; the Baystack 660 series and the Baystack 650 series. The 660 series is a 2 Mb/s DSSS system. Each access point supports up to 20 typical stations and has a coverage range of 100 meters indoors and up to 600 meters in an open environment. Access points can have overlapping coverage to provide 6 Mb/s bandwidth to stations. A picture of the 660 series PC card, as manufactured by Netwave (now a part of Nortel Networks) is shown in Figure 1 . This card fits into a standard PCMCIA card reader slot for maximum mobility and has an integrated antenna. Figure 2 shows a PC card used in an on-board computer in our tractor platform.

The 650 series support only a wireless-to-wired bridge that attaches to a LAN backbone. These products use 2.4 GHz FHSS radio transmission. Each access point supports 10 to 15 typical stations and the coverage range is up to 70 meters indoors and up to 300 meters in an open environment. The 650 products allow 10 or more overlapped access points for a high user density [2] The 650 series are not IEEE 802.11 compliant whereas the 660 series are.

Figure 2. PC in the tractor platform.

Another commercially available wireless networking product series is the WaveLAN family from Lucent Technologies. These products support 2.4 GHz DSSS only and are currently in their second generation. This generation, WaveLAN-II, supercedes the first generation, WaveLAN-I, which was introduced in 1991. WaveLAN-II supports the IEEE 802.11 standard bit rates of 1 Mb/s and 2 Mb/s, and can also support up to a 10 Mb/s rate [8]. At this high rate, the wireless LAN connection is equivalent to a wired Ethernet LAN. Like the Baystack 600 series, the WaveLAN-II comes in a PCMCIA card package and has an internal antenna. In addition, a connection is provided for an external antenna as shown in Figure 3.

Figure 3. WaveLAN PC card with external antenna

Software utilities and security features associated with the WaveLAN-II products are similar to those of the Baystack 600 series. The WaveLAN-II provides roaming within the area covered by various access points. Up to 40 users can access a single access point comfortably while using Windows and more than 100 users can connect, depending on the application. Coverage can extend up to 5000 square meters for a single access point by using the external antenna with the WaveLAN card [8, 14]. A WaveLAN access point is shown in Figure 4 with the antenna.

A third generation of WaveLAN products has been recently introduced, the WaveLAN-III.

Figure 4. WaveLAN Access Point

These products include the Omni directional base station antenna and vehicle antenna. With these antennas, coverage can be extended to a 2.5 km radius outdoors. The Omni antenna is used with the access point and offers a 7 dBi gain. The vehicle antenna offers a 5 dB gain and is shown mounted on the tractor cab in Figure 5.

Figure 5. Lucent Vehicle Antenna mounted on tractor platform

Research Platform

Two modified agricultural vehicles were used for this research. Both were similar in the array of sensors and type of control used for automation. Vehicle 1 is a Case 8920 Magnum[2] tractor, outfitted with positioning and orientation sensors. Our positioning sensor for this vehicle was a Novatel RTK-20 differential GPS receiver with 20 cm static accuracy. The platform also included a JAE 108-FD Fiber Optic Gyro (FOG) for sensing heading, and a Crossbow CXTA02 two-axis tilt sensor for detecting pitch and roll. The vehicle included an Elmo TSE 271 vision sensor, which was digitized by an Imagenation CX-100 frame-grabber and/or an ATI All-in-Wonder Pro video capture card. Vehicle two is a Case MX-240 tractor, outfitted in similar fashion. This tractor has the same vision system and heading, pitch and roll sensors, but uses a Trimble 4400 DGPS receiver, with 2 cm static accuracy. Vehicle 1 and Vehicle 2 are shown in Figures 6 and 7 respectively.

Figure 6. Research Platform “Vehicle 1”

Figure 7. Research Platform “Vehicle 2”

Voice Recognition System

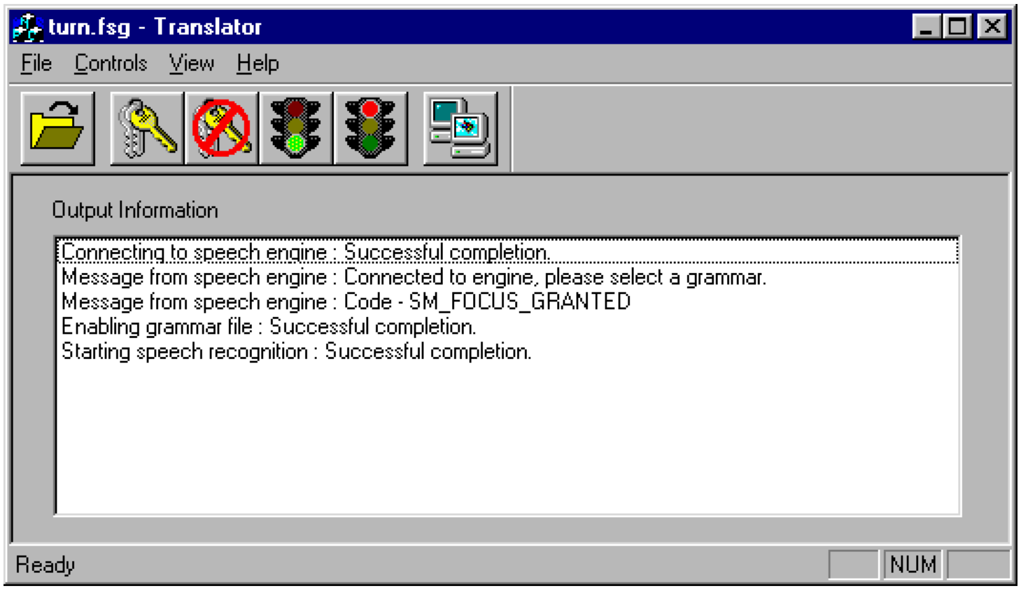
Voice recognition was incorporated into each system using the commercially available software package IBM ViaVoice. The software package includes a speech recognition engine, and several applications that integrate speech recognition with various standard applications such as word processing software and operating system control. The speech recognition engine was used to develop our own custom control software to interface with this engine. IBM makes several resources available to accomplish this goal, including the

---

[2] Case and Magnum are trademarks of the Case Corporation and are used with permission.

ViaVoice SDK and ViaVoice TopicFactory [7]. These products allow you to develop specific vocabularies for your application, and provide function calls directly to the speech recognition engine.

A higher-level interface for our applications was developed using a product made available by the National Center for Supercomputing Applications (NCSA) called Translator. The Translator software (available from [3]) forms a bridge between the speech recognition engine ViaVoice, and an existing TCP/IP network. The Translator software is provided with a grammar of speech to be recognized, and an IP address and socket number of a "listening" client. The Translator software, using the underlying ViaVoice engine, recognizes speech (and only speech in the current existing grammar), then sends the recognized text (in the form of a string of characters) over the existing socket to the client. In this way, the entire process of interfacing with the speech recognition engine as well as the handling of the networking, is abstracted out for the user. Our task was to create a client (on the research vehicle) that listens for strings over a TCP/IP network socket, parses them, and generates the appropriate response to the command. The Translator application window is shown in Figure 8.



```
Connecting to speech engine : Successful completion.
Message from speech engine : Connected to engine, please select a grammar.
Message from speech engine : Code - SM_FOCUS_GRANTED
Enabling grammar file : Successful completion.
Starting speech recognition : Successful completion.
```

Figure 8. Translator Software Application Window

The words and phrases for the Translator software to recognize are written in Backus-Naur Form (BNF) in an ASCII text file. This file is then compiled into a Finite-State Grammar (FSG) for use by Translator, using the speech compiler provided in the ViaVoice SDK [7]. The BNF grammar is easy to use and create. An example of the BNF used for one of our applications is shown in Table 1.

```
<root> = hard to <direction> |
        easy to <direction> |
        steady as she goes  |
        set throttle to <level> |
        <clutch_status> the clutch |
        set transmission to <gear> |
        set heading to <bearing> |
        set postion to point <point_name> |
        honk the horn |
        sound the alarm.

<direction> = starboard | port.
<level> = low | medium | high.
<clutch_status> = engage | disengage.
<gear> = reverse | forward low | forward high.
<bearing> = north | south | east | west | northeast | northwest | southeast | southwest.
<point_name> = alpha | bravo | charlie.
```

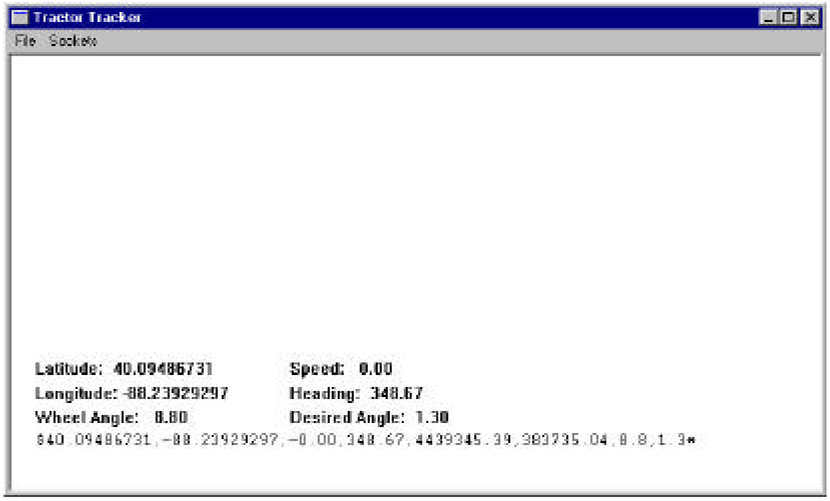
Table 1. Backus-Naur Form grammar example, as implemented in our system.

Vehicle Information Telecasting

One of the most simple and straight forward applications of wireless networking for off-highway equipment is to take the vehicle’s sensor information (position, heading, speed, etc) and make it available remotely in real time. Considerations for this include the types of information to make available, the transfer format, update rates, and medium of display. If many users will be connecting to the stream of information, bandwidth considerations may have to be taken into account. In this application, we need to consider both the mobile vehicle server format and the method client connection and display of the information.

We demonstrate two methods of telecasting. The first is a Java-based server which reads the position, speed, roll, pitch, and heading of the vehicle in real time at a rate of 2 Hz. The server waits for any client connections, and after connecting to a client, responds to any queries (for position, speed, etc.) by the client. The client can then use this information for updating the client’s display. Our example simply queries each of the state variables and displays them in textual form in a applet window. Since the client is written as a Java applet, the applet can be run in a web browser window. Further, the applet can be kept on the vehicles web server page, so that anyone wishing to observe the status of the tractor need only a Java-enabled browser and the correct URL of the applet.

The second form of telecasting that we present is a server on the vehicle that sends out a formatted string at regular intervals to any connected client. This enables the client’s implementation and display to be independent of the server itself; the client is always receiving the most recent data from all of the sensors at any given time. The client need only understand the format of the string it receives. Some examples of this would be a mapping program, which would read the position information from the string, and make a real-time map on the screen of the tractor’s location. A graphical depiction of the tractor could be implemented where the pitch, roll, heading, and speed of the tractor are all displayed. Perhaps the most interesting of the client applications would be to have a client with a GIS database of the terrain and surrounding area in which the tractor is operating. A 3-dimensional rendering of the terrain, tractor, and any obstacles could then be generated and displayed in virtual space. A window of an example program which reads the formatted string and displays information updates to the user is shown in Figure 9. The formatted string is shown below the variable read-outs for illustration purposes only. The blank area above the status variables is intended to be used as a mapping area, but is not yet implemented.



```
Latitude:  40.09486731        Speed:   0.00
Longitude: -88.23929297       Heading:  348.67
Wheel Angle:   8.80           Desired Angle:  1.30
$40.09486731,-88.23929297,-0.00,348.67,4439345.39,383735.04,8.8,1.3*
```

Figure 9. Example Program residing on a remote computer which reads the formatted strings and displays the desired information for the user.

Remote Voice-based Steering Control

A main part of this research involves the investigation of using the wireless network to control the steering of the vehicles. The method of control can take many forms, such as low-level control of the wheel angle itself, or higher-level control (such as indicating a path or heading to follow). The method of command can take many forms as well, such as keyboard input, mouse, or a steering simulator. In this work, we explore using voice-based commands for both high-level and low-level steering control of the vehicle.

Since a steering control system is already present on the vehicle, low-level steering control is a straight forward task. We simply include commands in the control grammar such as “Steer Right,” “Go Straight” or “Turn Wheels to Fifteen Degrees.” After being recognized by the speech software and sent over the TCP/IP socket using Translator, the phrase is

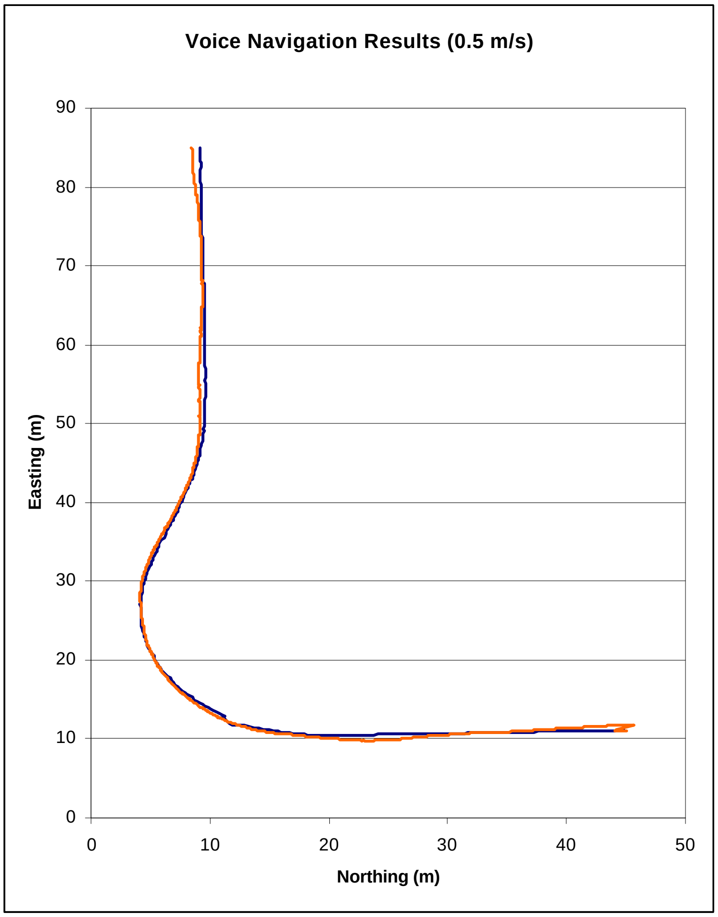


Figure 10. Results of Voice-based Steering Control Using Low-level commands

then parsed by the on-tractor computer, which then generates the appropriate output to the electrohydraulic valve using the already-developed steering controller. This scheme of control assumes that the operator has either visual contact with the vehicle or some other sort of feedback (such as streaming video over the wireless connection) in order to control the vehicle appropriately. Figure 10 shows the results of an attempt to navigate along a given path using only low-level steering control commands.

A second level of voice-based control for agricultural equipment involves high-level commands. Examples of higher-level control commands would be “Set Heading to Ninety Degrees,” “Execute End of Row Turn,” and “Follow Third Cropline.” Execution of such commands depends on a Navigation system on the tractor capable of completing the actions, but the method of command works exactly the same.

In this research project we have demonstrated both low- and high-level commands. The conclusions drawn from the actual execution of these is that high-level commands are far more successful for actual applications. The delay associated with the recognition and transmission of the low-level commands makes it very difficult for a human to negotiate a given path using only a “voice-base steering wheel.” This type of control boils down to a very low frequency control loop (< 1 Hz.) High-level commands such as “Set Bearing to North” have shown much greater promise, since it allows the on-board computer to implement a fast control loop (> 50 Hz) for executing the command. However, at low speeds (< 1 m/s), low-level steering commands were found to be quite successful.

Conclusions and Future Work

Wireless networking products show great promise for automation of off-highway equipment. The advent of low cost, high bandwidth and high coverage area make them well suited for many applications, including information telecasting and remote-based control. Further, the modularity of these products and their use of standard protocols allow easy incorporation of standard software, and assure compatibility with future wireless technology.

Remote voice-based steering control was demonstrated on an agricultural vehicle. It was found that low-level steering commands were well-suited for lower speeds, but the time delay in the control loop was insufficient for curved paths at speeds greater than 1 m/s. High-level steering controls worked well for arbitrary speeds. Further, vehicle data telecasting was successfully demonstrated for this vehicle. The modular design of formatted string broadcast was shown to be an ideal method for this task, as it allows any type of client to connect to the tractor server, and display the information in any format. We demonstrate both a Windows-based and Java-based client for this telecasting server.

The wide range of possibilities in this area leave much room for future work. In our research, we wish to continue the work on high-level commands for steering control on our platforms. Also, we plan to demonstrate cooperative task completion using the wireless link between two or more vehicles and a base station. Further, we wish to more closely integrate the vehicle information telecasting with the remote based control to provide a fully remote closed loop for control. The most compelling task we are faced with is to use the telecasting of dynamic vehicle information in constructing a real-time virtual environment, and executing voice-based control of the vehicle simultaneously.

Acknowledgements

This research was supported by USDA Hatch Funds and Illinois Council on Food and Agricultural Research (99Si-036-1A). The mentioned supports are gratefully acknowledged.

References

[1] Baldazo, R. “Local air networks *Byte*, v. 20, June 1995, p. 201-2.

[2] "Baystack 600 series wireless LAN products" Nortel Networks. website: http://www.baynetworks.com/products/datasheets/3151.pdf, June 21, 1999.

[3] Bock, David “NCSA Speech Translator,” National Center for Supercomputing Applications. Website: http://woodall.ncsa.uiuc.edu/dbock/Tools/Translator/, June 21, 1999.

[4] Boller, C. “State of the art and trends in using smart materials and systems in transportation vehicles *Proc. of the Institution of Mechanical Engineers. Part I, Journal of Systems & Control Engineering*, v. 212, no. 13, 1998. p. 149-58.

[5] Crow, B. P., I. Widjaja, J. G. Kim, and P. T. Sakai. "IEEE 802.11 wireless local area networks" *IEEE Communications Magazine*, v. 35, no. 9, Sept. 1997. p. 116-26.

[6] Gai, E. “Guidance, navigation, and control from instrumentation to information management *J. of Guidance, Control, and Dynamics*, v. 19, no. 1, Jan.-Feb. 1996. p. 10-14.

[7] “IBM ViaVoice SDK for Windows”, IBM Corporation. Website: http://www.software.ibm.com/is/voicetype/dev_vvsdk.html, June 16, 1999.

[8] Kamerman, A. and L. Monteban. “WaveLAN®-II: A high-performance wireless LAN for the unlicensed band” *Bell Labs Technical Journal*, v. 2, no. 3, Summer 1997. p. 118-33.

[9] LaMaire, R. O., A. Krishna, P. Bhagwat, and J. Panian. "Wireless LANs and mobile networking: standards and future directions" *IEEE Communications Magazine*, v. 34, no. 8, Aug. 1996. p. 86-94.

[10] Nath, M. “IEEE-802.11 standard accelerates wireless-LAN development *EDN*, v. 41, Dec. 5 1996. p. 20

[11] Rash, W. Jr. “WaveLAN: A network with no strings attached *Byte*, v. 16, no. 6, June 1991. p. 294-6.

[12] Shladover, S. E. “Research and development needs for advanced vehicle control systems" *IEEE Micro*, v. 13, no.1, Feb. 1993. p. 11-19.

[13] Stone, M. L., K. D. McKee, C. W. Formwalt, and R. K. Benneweis. "ISO 11783: An electronic communications protocol for agricultural equipment" ASAE Distinguished Lecture Series, presented at Agricultural Equipment Technology Conference, Louisville, Ky. Feb. 7-10, 1999.

[14] "WaveLAN wireless LAN technology and market backgrounder" Lucent Technologies. website: ftp://ftp.wavelan.com/pub/docs/ieee/bulletin/sales/sb_backg.pdf, June 16, 1999.