Vehicle on Wireless Sensor Network

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Abstract: - To facilitate intelligent traffic communication, a reliable, realistic, and network is required for ad-hoc communication between vehicles. Many requirements compete in the different existing vehicular networking systems. However, one solution to suit all purposes has not been determined. While the vehicle-to-infrastructure, such as standardized GPRS, HSPAm, and LTE, is currently used, vehicle-to-vehicle and vehicle-to-roadside units are more or less under construction. In addition to connections to server/traffic centers, connections to local sensors and traffic signs are needed to obtain actual and local information in changing environments. In this paper, we describe the results of tests using wireless sensor network (WSN) radios of different kinds to communicate with moving vehicles. Our aim is to provide measured background information about different kinds of vehicular networking methodologies in order to find an optimal solution for different kinds of usage scenarios.

Keywords: vehicle-to-vehicle communication, sensor network

1 Introduction

The field of vehicular networking and communicating roadside units is widely studied nowadays. As this technology has emerged, many types of usage needs, services, and communication systems have been envisioned and constructed. In the simplest case, vehicular networking refers to roadwork areas where wireless devices broadcast warning information to approaching vehicles. On the other hand, vehicular communication can also mean that vehicles receive up-to-date traffic-related service information from the roadside unit while transmitting newly collected observation data to update the same services. It is obvious that a single communication system cannot meet all types of usage needs.

In this paper, we will compare the use of different frequencies and protocols when a vehicle needs to be part of a wireless network with roadside sensors. The objective of this study was to find an optimal solution or solutions for different uses of roadside units, which vary from a simple roadwork warning system to intelligent, interactive roadside unit service stations.

Furthermore, there is always insufficient room inside the vehicle to install aftermarket radios. During the experimental tests we also change positions to analyze the effect if the radio is not installed in the optimal place.

2 State-of-the-art

Currently, IEEE 802.11p (WAVE) has been widely utilized in V2I communication-related ITS field tests [1]. One of the first tests was made by Denso Corporation, in which a mobile terminal communicated with a server without disconnection [2]. After years of investigation, many challenges still exist. Performance measurements conducted by Paier et al. [3] showed that environmental effects, such as antenna height, electromagnetic wave propagation effects, and traffic severely affected performance in WAVE-based V2I communication. Most previous experiments have been executed on highways. Govalvez et al. [1] reported that the use of WAVE in urban areas requires the efficient deployment of infrastructure nodes for the use of V2I communication in cooperative vehicular services. In addition, the results of previous tests showed that WAVE still has limitations that have to be taken into account. Designers should be aware that street layout, terrain elevation, traffic density, and the presence of heavy vehicles, trees, and vegetation increase the complexity of ITS services in urban areas. Typical areas in which V2I communication can be applied are the detection of obstacles, pedestrians, road surface conditions, road signals, advertisements, and safety and warning signs [4].

Currently, one of the largest WAVE implementations is being designed in a European FP7 project called Drive C2X. This project will utilize WAVE technology in both V2I and V2V communication in seven European Union countries: Finland, Sweden, Germany, Netherlands, France, Italy, and Spain [5]. Moreover, the Car2Car Communication Consortium [6] has emphasized the importance of wireless LAN. In the United States, the Department of Transportation Research and Innovation Technology Administration has made plans to start with V2I while migrating V2V capabilities gradually. One DSRC radio at 5.9 GHz will be used in all applications [7]. However, they have posed two open research questions for ITS researchers: 1) Would V2V and V2I work technically? and 2) Could these technologies be implemented practically? According to Karagianis et al., [8] the first ITS services used a frequency spectrum between 902 MHz and 928 MHz. Because this band was too small, the frequency area was later replaced by 5.9 GHz. In Japan, the ITS-Safety program is expected to introduce the frequency band of 700 MHz for V2V safety applications. Furthermore, in the Smartway program, the frequency band of 5.8 GHz has been largely tested and deployed for e-payment, traffic information, and warning services [8].

In our previous studies, we gathered experiences of WAVE technology in both V2V and V2I communication [9]. We also worked with roadside sensors at a frequency of 868 MHz in order to visualize collected sensor data, such as weather, driver, and vehicle information by utilizing the Nokia Terminal Mode [10]. Therefore, based on this short state-of-the-art review, we were encouraged to compare UHF and WAVE technologies in V2I communication. Our objective was to find the most appropriate solutions for different usage needs for vehicles in traffic.

The vehicular environment imposes a set of new requirements on today's wireless communication systems. Vehicular safety communication applications cannot tolerate long connection establishment delays before being enabled to communicate with centralized safety systems and/or other vehicles on the road. Because of the limited time it takes for a car to drive through the coverage area, non-safety applications also demand an efficient connection setup with roadside stations that provide services (e.g., weather data update). Additionally, rapidly moving vehicles and complex roadway environments present challenges at the physical level. These problems are typical in using “office-oriented” protocol versions of IEEE 802.11; nowadays 802.11n and 802.11g are the most common ones. The IEEE 802.11 standard body has produced a new amendment, IEEE 802.11p, to address these concerns. This standard is called wireless access in vehicular environment, also known as WAVE. The underlying technology in this protocol is dedicated short-range communication (DSRC), which is essentially the IEEE 802.11a standard adjusted for low-overhead operations. The primary purpose of the DSRC is to enhance public safety applications, save lives, and improve traffic flow by vehicle-to-vehicle and infrastructure-to-vehicle communications.

3 Wireless Sensor Network

The wireless sensor network (WSN) (IEEE802.15.4) [11] is a low-range, low-cost wireless network. The sensor network allows fast connection when it is needed in vehicle-to-vehicle and vehicle-to-roadside units. The locations of transmitters and receivers are important. When radio waves propagate a line of sight route, they encounter fewer problems when there is an intervening chassis or other structure.

Sensor messages require only a short time to be delivered from the infrastructure to the vehicle. For instance, weather information or warnings about upcoming obstacles or accidents can be delivered efficiently by only a few dozen bytes. Wireless communication with WSN reacts easily in changing network structures where moving nodes disappear and then reappear, and it manages connections automatically.

However, some disadvantages should be noted. For independently operating roadside units, energy consumption could be an issue without a main connection or solar panel. Low processing capability avoids using low transmitting power, thus decreasing the possible communication distance. It also shortens data transfer time between vehicle and roadside unit.

European laws restrict transmitting on wireless channels. Continuous transmitting is required when trying to contact a car driving by. Some restrictions on continuous transmission are that frequencies avoid broadcast-type transmission at frequency 868 MHz and allow transmission only 0,1% of the time. ISM-channels are more usable because everyone could transmit with low power units. For traffic information ISM-channels on frequencies 433 MHz, 916 MHz, 2,4 GHz and 5,8 GHz are promising, in addition to 5.9 GHz, which dedicated for vehicular networking purposes.

During propagation, radio waves encounter problems. First, the signal will attenuate by one fourth every distance multiplied by two. Hence, the communication range is always limited because the transmission power is restricted.

Several transmitters within same frequency could transmit simultaneously over other, causing their waves to interfere with each other. Consequently, a single wave could not be recognized. Radios note this situation as a crash and send the messages again.

Particularly in vehicle traffic, moving radios cause frequency transfer because of the Doppler effect. When the difference in speed between the approaching transmitter and the receiver increases, the frequency received increases. When the vehicle passes a roadside unit or another vehicle, the frequency received decreases. Higher speeds cause problems by both receiving locking correct frequency and shortening the time to drive by, that is, the total time required to find the transmitter, get connected, and receive the data decreases dramatically.

4. Evaluation

In the field test, we mobilized 868 MHz and 443 MHz as well as 5,8G Hz radio frequencies to determine how the location of the radio in vehicle, the driving speed, and frequency affected transmission. Using receiver software, we measured the total connection time and transmitted data as frames. Using a GPS-based measurement device, we also measured the distance that the car travelled during connection.

4.1. 868 MHz radio tests

We used a Microchip MRF89XAM8A radio with a 20 mW, 43 byte data frame. The transmitter was located 30 meters away from the road at a height of 2,5 meters.

The transmitter sent broadcast-type frames continuously every 250 milliseconds. The receiver was located over the dashboard of the vehicle to provide a line-of-sight connection to the transmitter. The total connection time and the average rate of the data transfer are shown in Table 1.

Vehicle Speed	Connection time	Avg. Throughput when connection (kb)	Avg. Throughput during session (kbps)
76	0:00:19	17,13	0,9
89	0:00:16	13,44	0,8
100	0:00:13	13,44	1,0

Table 1. 868 MHz Radio receive broadcast above dashboard.

The comparison receiver was located under the right front seat. As shown in Table 2, the connection times and amount of received data decreased

Vehicle Speed	Connection time	Avg. Throughput when connection (kb)	Avg. Throughput during session (kbps)
72	0:00:10	13,77	1,4
82	0:00:16	11,09	1,2
95	0:00:08	8,73	1,1

Table 2. 868 MHz radio receive broadcast under seat.

Next, we changed the type of sending packets, so the transmitter would not transmit continuously. Instead, the receiver sent queries when it contacted the transmitter. When the transmitter recognized a query, it answered by sending data frames (Table 3). Hence, the energy of the battery-powered roadside sensor could be saved. The receiver queried the data frame to send continuously every 250 ms. The receiver was located on the dashboard of the vehicle

Vehicle Speed	Connection time	Avg. Throughput when connection (kb)	Avg. Throughput during session (kbps)
79	0:00:22	22,51	1,0
81	0:00:19	22,84	1,2
92	0:00:16	17,13	1,1

Table 3. 868 MHz radio queries above dashboard.

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The vehicle proceeded a distance of 450 meters during the connection time at all speeds mentioned at table 3.

We again changed the location of the receiver to under the passenger seat. Table 4 shows how the throughput again decreased slightly when radio was covered. The receiver queried the data frame to send continuously every 250 ms.

Vehicle Speed	Connection time	Avg. Throughput when connection (kb)	Avg. Throughput during session (kbps)
81	0:00:11	14,45	1,3
86	0:00:10	14,78	1,5
90	0:00:09	11,76	1,3

Table 4. 868 MHz radio queries under seat.

The total distance during connection was reduced by almost half from 240 m to 300 m.

During the test, we also noticed that the connection was very reliable under communication. The communication time decreased when the line-of-sight connection was lost because of the location of the radio.

4.2. IEEE 802.11p tests

Finnish Meteorogical Institute (FMI) conducted 76 measurement drives with IEEE 802.11p-based equipment in Sodankylä, Finland. All the measurements were conducted in similar weather conditions. In each measurement, the vehicle bypassed the roadside unit, maintaining the connection with it as long as possible and with the highest possible data rate.

Vehicle speed	Connection time	Avg. Throughput when connection (Mbps)	Avg. Throughput during session (Mbps)	Connection availability %
70	42,437	1,519	0,627	41,257
80	38,442	1,527	0,652	42,713
90	33,280	1,531	0,637	41,600
100	30,320	1,530	0,644	42,111

Table 5 IEEE 802.11p communication measurements.

Table 5 shows a summary of the field measurement results, including the range of the communication in terms of connection availability. We determined the ideal communication availability time based on a theoretical range of 1000 m. The communication availability was the relation between the achieved result and the ideal case. The connection availability remained around 41%, which indicated that the true range is clearly smaller than the theoretical one. By calculating the average range of all V2I measurements conducted, we derived the 420 m range observed in FMI measurements.

4.3 433 MHz radio tests

We used Microchip MRF49XA installed on a PIC 18 Explorer Board. We used a 40-byte data frame. We started the test with two transmitters and one receiver. In addition, we calculated the transmitted data from the roadside transmitter. The objective of these tests was to discover whether another transmitter nearby would cause problems during transmission. Another transmitter was located differentially in various positions to see how it would harm the receiving packets. A fixed transmitting power was set at 1 mW for both transmitters.

At first, both transmitters eventually sent broadcast packets without specific queries in advance. Thus, there were continuous transmissions without any role for the vehicle's receiver

The receiver was located over the vehicle's dashboard. The measurements are shown on Table 6. The transmitters were located 20 meters apart along the roadside .

Vehicle Speed	Connection time	Avg. Throughput during connection (kb)	Avg. Throughput during connection (kbps)
80,00	0:00:16,550	6,72	0,406
100,00	0:00:12,932	5,16	0,399

Table 6. 433 MHz transmitters on roadside.

We continued with the receiver on the dashboard. Table 7 shows how we changed to another roadside transmitter inside the car in the center of the cabin near the roof. Both transmitters were programmed to send data continuously to a maximum amount of data every 250 milliseconds.

Vehicle Speed km/h	Connection time	Avg. Throughput during connection (kb)	Avg. Throughput during connection (kbps)
80,00	0:00:12,620	6,25	0,495
100,00	0:00:09,198	4,69	0,510

Table 7. Another 433 MHz transmitter inside car.

We changed the location of another transmitter from inside the car to the engine bay. The measurements are shown in Table 8. Both transmitters sent maximum amounts of data in a given sequence, and the receiver remained on the dashboard.

Vehicle Speed km/h	Connection time	Avg. Throughput during connection (kb)	Avg. Throughput during connection (kbps)
80,00	0:00:11,652	5,78	0,496
100,00	0:00:09,198	4,69	0,510

Table 8. Another 433 MHz transmitter on engine bay

Finally, we changed the location of the vehicle transmitter to the trunk of the car. One roadside sensor and receiver remained in their line-of-sight locations. The packets received from the roadside transmitter are shown in Table 9.

Vehicle Speed km/h	Connection time	Avg. Throughput during connection (kb)	Avg. Throughput during connection (kbps)
80,00	0:00:10,238	5,47	0,534
100,00	0:00:07,118	4,22	0,593

Table 9. Another 433 MHz transmitter on trunk.

For the next series of tests, we changed the location of the receiver from the dashboard to under the right front passenger seat. Similar to 868 MHz, we simulated a situation in which the radio in the vehicle cannot be installed in the optimal location. We repeated the tests described earlier for these positions.

Vehicle Speed km/h	Connection time	Avg. Throughput during connection kbps	Avg. Throughput during connection kbps
80,00	0:00:10,826	4,53	0,419
100,00	0:00:06,886	3,44	0,499

Table 10. Receiver under seat. Both transmitters at roadside

To start, both transmitters were again on the roadside, located 20 meters apart. They sent the maximum amount of data every 250 milliseconds. The measurement results are shown in Table 10.

In the next text, the receiver was held under passenger seat. The transmitters were installed both inside the glove compartment and at the roadside. As shown in Table 11, the lowest throughput was indicated here.

Vehicle Speed km/h	Connection time	Avg. Throughput during connection (kb)	Avg. Throughput during connection (kbps)
80,00	0:00:04,342	2,81	0,648
100,00	0:00:04,466	2,81	0,630

Table 11. Another 433 MHz transmitter radio on cabin

Another transmitter was moved to the engine bay (Table 12). The receiver was located under the seat, and the roadside transmitter was located in the same position as before.

Vehicle Speed km/h	Connection time	Avg. Throughput during connection (kb)	Avg. Throughput during connection (kbps)
80,00	0:00:08,874	5,00	0,563
100,00	0:00:19,446	3,44	0,177

Table 12. Another 433 MHz transmitter on engine bay

The location of the transmitter in the vehicle was moved from the engine bay to the trunk (Table 13). Both transmitters sent data every 250 milliseconds. The receiver was located under the seat.

Vehicle Speed km/h	Connection time	Avg. Throughput during connection (kb)	Avg. Throughput during connection (kbps)
80,00	0:00:06,678	3,75	0,562
100,00	0:00:06,578	3,13	0,475

Table 13. Another 433 MHz transmitter on trunk

While programming the radios, we noticed that if both radios were programmed to transmit simultaneously, only packets from another radio could be received. We still wanted to use two transmitters in order to simulate a situation in which several radios could be heard at same time. When we slightly changed the transmitting intervals between the radios, transmission became possible. These tests showed how collisions destroy still packets during transmission, and the packets will loose. The results indicated that the number of transmitted frames that reached receiver was sufficient to make viable communication possible.

5. Conclusion

In this paper, we compared the use of different frequencies and protocols when a vehicle is part of a wireless network with roadside sensors. Based on our field measurements, we generated a proposed solution for each usage scenario envisioned. Naturally, our suggestions are limited only to the communication methods included in our field tests.

In the case of the roadside unit developed in WiSafeCar project [12], which interactively operated with vehicles and the service core in the network, exchanging up-to-date data between these entities, the IEEE 802.11p solution operating in the 5.9 GHz band is clearly the most efficient solution. It allows a relatively large range with more than 45 Mbps of data exchange during the bypass at a speed of 100 km/h speed. In general, when the data exchange requirement during the bypass exceeds the megabit-level, the IEEE 802.11p, designed particularly for this purpose, is the preferred solution.

In the case of roadwork warnings using a simple broadcasting transmitter, the low-cost, low-energy 433 MHz wireless sensor network seems to work flawlessly. Its low transmission power decreased the distance reached, but lower frequency compensated and the necessary throughput was accomplished. Traffic lights with advanced features enabled through a wireless network have somewhat different requirements. The capacity does not need to be high, but the range is more important. In this case, IEEE802.11p seems to fulfill these requirements if enough energy is available from the light system.

A future study should perform more measurements within a maximum available connection range.

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