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MEASURING AND USING THE RSSI OF IEEE 802.11P

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ABSTRACT

The scalability of intelligent transport systems (ITS) applications is difficult to test in a field operational test (FOT) due to the high number of ITS equipped vehicles required. Therefore, computer simulations for evaluating different wireless communication technologies for ITS different applications can serve as a complement. In this paper we present results from lab measurements conducted on the CVIS hardware platform equipped with the upcoming standard IEEE 802.11p. We have measured the packet error rate versus the signal-to-noise ratio (SNR) for different packet lengths. This lab measurement is the first step towards an outdoor measurement campaign which also considers interference. The outdoor measurements will then be fed into a computer simulator together with a realistic channel model for evaluating the scalability of VANETs in a highway scenario.

INTRODUCTION

There is an immense activity all around the world within ITS concerning applications for increasing traffic safety and efficiency using vehicular communications: so-called cooperative systems. Depending on application, different wireless access technologies will be used, such as 2G/3G, infrared (IR) and IEEE 802.11p. Many traffic safety applications will be based on direct vehicle-to-vehicle (V2V) communications in an *ad hoc* network structure, i.e., a vehicular *ad hoc* network (VANET). IEEE 802.11p, to be ratified during 2010 (1), will be the standard for the first generation of VANETs in many parts of the world. IEEE 802.11p is also the basis for the work conducted in ISO, termed CALM M5, as well as in the European standardization activities within ETSI TC ITS where it is called ITS-G5. An *ad hoc* network implies that no access points or base stations are required. This is in contrast to cellular systems, where all data traffic always has to traverse the base station even when the two nodes that want to communicate are within radio range of each other. The *ad hoc* nature of 802.11p

imposes additional requirements on the network to self-organize, support a varying number of nodes, and provide distributed channel access. Therefore, it is very important to evaluate the IEEE 802.11p based on these criteria. However, there are many open issues making the evaluation of 802.11p difficult: What are the application requirements in terms of system response time? When and how often should the vehicles communicate? How much data is generated and must be communicated? How far should for example an emergency message propagate? For which applications are multi-hop communication needed? The list of questions can be made long.

One key concept of decentralized VANET, such as the considered IEEE 802.11p systems, is *scalability* (2). To be scalable implies that the network must support a varying number of nodes without collapsing. In the early stages of the introduction of cooperative systems for enhancing traffic safety, the applications must work well even at low penetration rates. Conversely, when the penetration rate increases, the applications must scale accordingly and degrade gracefully. The broadcast nature of many ITS applications together with the distributed system requirements and harsh communication environment makes the scalability issue extremely challenging and important. The planning of large field operational tests (FOTs) for evaluating cooperative systems is currently under way in Europe. The goal of these FOTs is to test the feasibility of using vehicular communications in different scenarios and applications. However, evaluating the scalability of a VANET in an FOT is difficult due to the high number of ITS equipped vehicles required. Therefore, it is necessary to complement FOTs with computer simulations to evaluate the scalability of different wireless access technologies.

To build a good computer simulator for evaluation of the scalability of ITS applications using in VANETs, a realistic channel model is needed. We will be using the model in (3) which is based on real channel sounding measurements in various environments and models the radio wave propagation when vehicles communicate with each other in, e.g., a highway scenario. However, to use this model a curve that describes the packet error rate (PER) as a function of the signal-to-interference-and-noise ratio (SINR) is needed. This curve can be obtained through an outdoor measurement campaign. In this paper we present initial results from lab measurements representing the first step towards such an outdoor measurement campaign. The lab measurements are conducted on the CVIS hardware platform equipped with Atheros 802.11p chipset, where a cable acts as the transmission medium. This results in a noisy but interference-free and stationary channel and therefore the PER is obtained as a function of the signal- to-noise ratio (SNR), rather than the SINR.

IEEE 802.11p

Wireless access in vehicular environment (WAVE) is the protocol stack concept for vehicular communications developed by IEEE. It contains a medium access control (MAC) and physical (PHY) layer derived from IEEE 802.11 (4) called 802.11p, a new transport/network layer protocol (IEEE 1609.3), security issues specified in 1609.2, channel usage in 1609.4 and an application protocol called 1609.1. The MAC method of the 802.11p is a carrier sense multiple access with collision avoidance (CSMA/CA) derived from 802.11, and 802.11p will also use the Quality of Service (QoS) amendment 802.11e, Fig. 1. The PHY layer of 802.11p is the 802.11a, based on orthogonal frequency division multiplexing (OFDM), with some minor changes to fit the high-speed vehicular environment. The 802.11p together with the 1609.4 standard is designed for 10 MHz wide channels instead of 20 MHz as it is in the original 802.11a. Due to this, the transfer rates will be halved in 802.11p compared to 802.11a, implying transfer rates of 3, 4.5, 6, 9, 12, 18, 24, and 27 Mbps. The different transfer rates are obtained through changing modulation scheme and channel code rate. The narrower frequency channel is an effort to decrease the inter-symbol interference (ISI) in the outdoor channel. Another major difference in 802.11p compared to the original 802.11 is that there is no difference between the nodes in the network, i.e., all nodes are peers including the roadside units. There exists no access point functionality in 802.11p even though the vehicular network will contain roadside units at certain spots.

In CSMA of 802.11p, each node initiates a transmission by listening to the channel, i.e., performs a carrier sense operation, during a predetermined listening/sensing period called the arbitration interframe space (AIFS), T_{AIFS} . If the sensing is successful, i.e., no channel activity is detected, the node transmits directly. If the channel is occupied or becomes occupied during the sensing period, the node must perform a backoff procedure, i.e., the node has to defer its

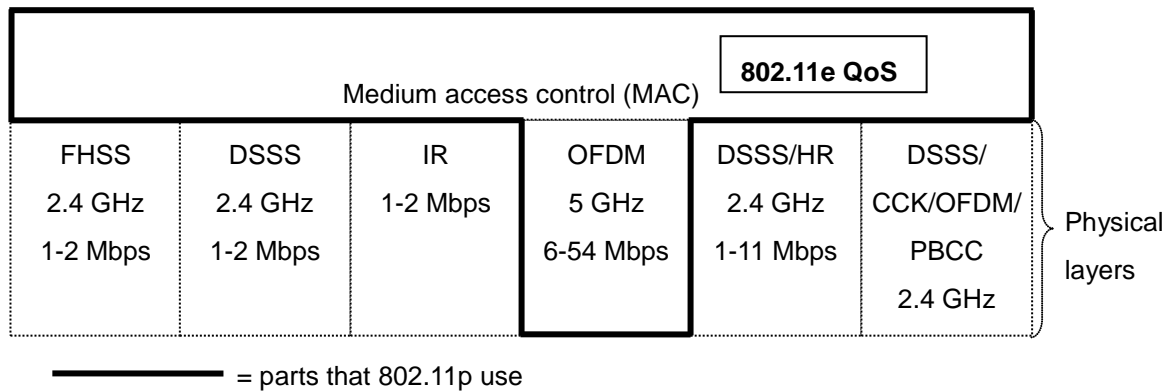


Figure 1. An overview of the WLAN family 802.11, showing in bold which parts that 802.11p will use and modify.

access a randomized time period. The backoff procedure works as follows: (i) draw an integer from a uniform distribution $[0, CW]$, where CW refers to the current contention window, (ii) multiply this integer with the *slot time*, T_{slot} , derived from the PHY layer in use (i.e., in 802.11p $T_{slot}=13\ \mu s$), and set this as the backoff value, (iii) decrease the backoff value by one *slot time* when a carrier sense operation declares the channel as free, (iv) upon reaching a backoff value of 0, send immediately. Hence, after a busy channel becomes free, all nodes must perform a carrier sense operation, i.e., listen T_{AIFS} , before decrementation of the backoff value can resume.

The MAC protocol of the original 802.11 is a stop-and-wait protocol and therefore the sender awaits an acknowledgment (ACK) that the transmitted packet has been correctly received before transmitting the next packet. If no ACK is received, which happens if the transmitted packet never reaching the recipient, if the packet being declared incorrect at receiver, or if the ACK being lost or corrupted, a backoff procedure is invoked before a retransmission is allowed. For every attempt to send a specific packet, the size of the contention window (CW) will be doubled from its initial value (CW_{min}) until a maximum value (CW_{max}) is reached. After a successful transmission or when the packet had to be thrown away because the maximum number of channel access attempts was reached, the contention window will be set to its initial value again. This is due to the fact that during high utilization periods, it is convenient to spread the access attempts in time. In a broadcast situation, i.e., when packets destined for all nodes are transmitted, none of the receiving nodes will send ACKs in response. Therefore, a sender never knows if anyone has received the transmitted packet correctly, and it will perform at most one backoff (which occurs when a busy channel is sensed at the initial channel access attempt). Hence, at most one backoff decrement will take place for broadcasted packets.

CVIS HARDWARE PLATFORM

Cooperative Vehicle-Infrastructure Systems (CVIS) is an EC funded FP6 Integrated Project (5), running between 2006 and 2010. One of the project objectives was to create a unified technical solution allowing all vehicles and infrastructure elements to communicate with each other in a continuous and transparent way using different wireless communication technologies. To fulfill this objective the Communication Access for Land Mobile (CALM) communication architecture was chosen as a basis (6). CALM is a set of standards under specification in ISO TC 204 WG 16. The scope of CALM is to provide a standardized set of air interface protocols and parameters for medium and long range ITS communication using one or more of several available media. The upper layer protocols of CALM are responsible for the transfer of communication sessions between different access technologies in a transparent way. As such CALM is not a single standard, but an inter-related set of protocols,

procedures and management processes.

As vehicles are travelling: urban via suburban to rural, we cannot expect a single wireless communication interface to cover all needs in all situations. Also the different applications have different communication needs. ITS safety applications often requires a low-latency direct communication between vehicles, ITS efficiency might require broadcast within a geographical area, while infotainment often requires continuous IP-based communication. To cover all these needs the CVIS communication platform implements the following communication interfaces found in CALM; 3G cellular, CALM M5 (5.9 GHz), and CALM IR. The basis for CALM M5 is IEEE 802.11p. In Figure 2, one of the communication boards in the CVIS box is depicted containing amongst other things a GPS receiver, the Atheros 802.11p chipset (CALM M5) and support for the electronic toll collection system in Europe called dedicated short-range communication (DSRC).

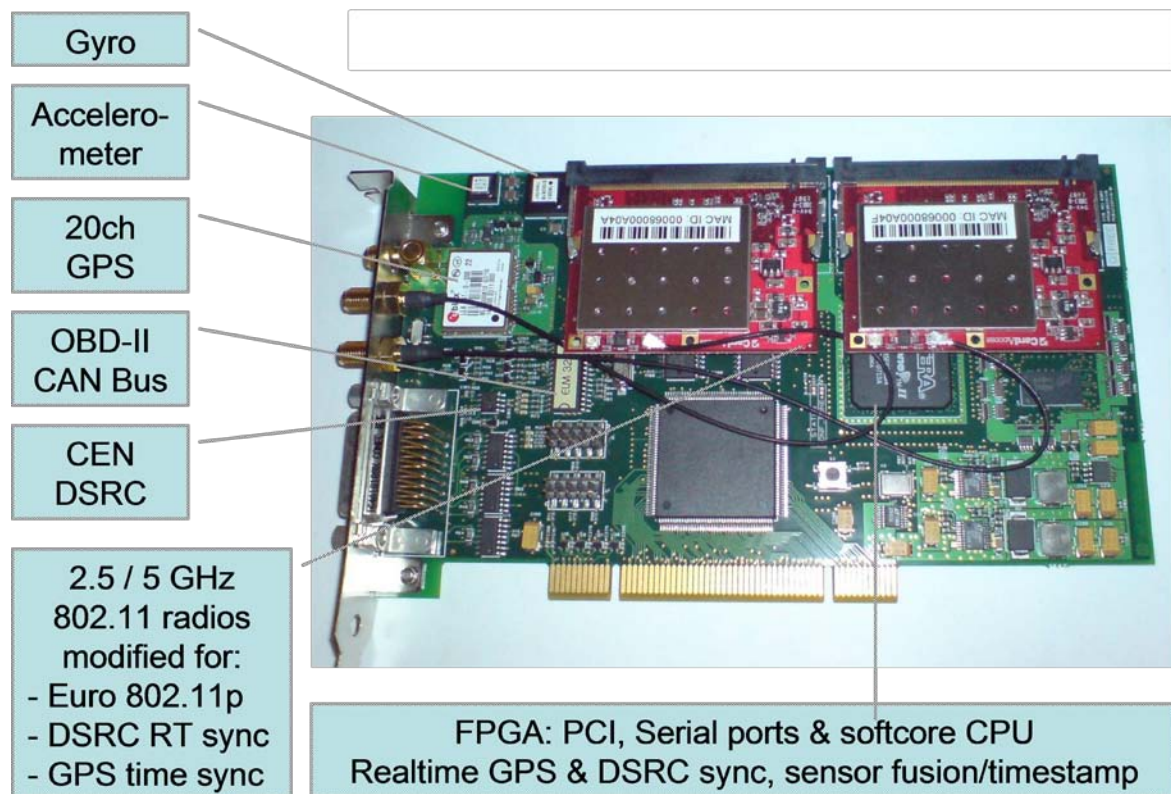


Figure 2. An overview of one of the communication boards in the CVIS box.

The communication architecture developed within CVIS was based on commercial-off-the-shelf (COTS) hardware using open source software. The complete communication system was available as a prototype device to various testbeds and field trial sites during the project. It is also available to other projects and actors as an open reference design through open source IPR agreements. The CVIS box is shown in Figure 3.



Figure 3. The CVIS box.

LAB SETUP AND MEASUREMENT RESULTS

The lab setup consists of two CVIS boxes connected with a cable in combination with a stepped power attenuator, Figure 4. The channel is therefore interference free and non-time-varying during the measurements. The two boxes communicate using the Atheros chipset 802.11p, one box act as a transmitter and the other one as a receiver. The outcome of the tests are the PER versus SNR for different packet lengths.



Figure 4. The lab setup.

To find the signal strength for achieving the SNR, we used the fact that the IEEE 802.11 has the ability to deliver a parameter called received signal strength indicator (RSSI) to higher layers. This value is used by the internal circuitry of the chipset to determine if e.g., the channel is busy or not during carrier sensing. The RSSI value is an integer and it has an allowable range of 0-255. It is up to the chipset manufacturer to determine how to use the RSSI parameter, i.e., how to convert the received signal strength (measured in, e.g., dBm) into an integer value. The RSSI value is measured in the preamble of the receiving packet and not continuously during the whole packet transmission. As soon as a preamble is detected, the

receiver signals to the MAC layer that there is activity on the wireless channel and it also states the RSSI value that has been detected. The Atheros chipset has a straightforward method for using the RSSI value namely by relating it to the SNR, i.e., the integer value of RSSI represents the number of dB above the noise floor.

In Figure 5 the results from the measurements are shown as the PER versus SNR for different packet lengths when a transfer rate of 6 Mbps have been used. The packet lengths chosen are 100, 300, 500 and 723 byte. The different packet lengths represent typical lengths for proposed ITS applications. However, the size 723 byte is due to the outdoor measurement campaign not allowing higher values. The fixed transfer rate is chosen because most standardization activities seems to have this preferred rate for data traffic generated by traffic safety applications, especially, the position messages proposed in Europe called cooperative awareness messages (CAM). The noise floor in the measurements has been around -110 dBm. The RSSI value, which can be directly converted into signal strength in dBm, has not been verified against a power meter and therefore the results here should only be considered as a relative measure.

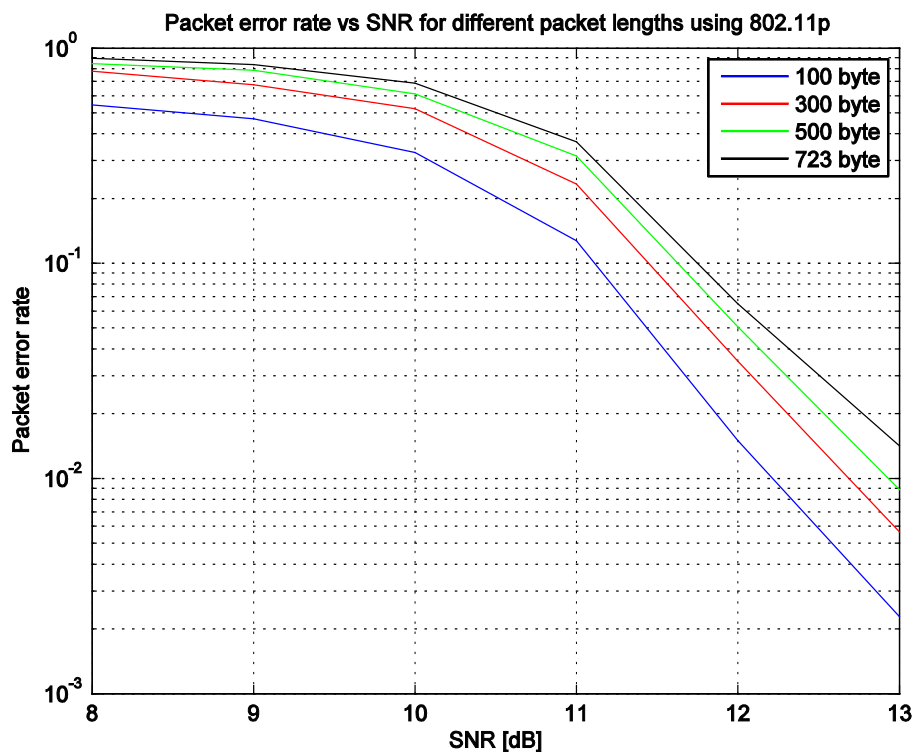


Figure 5. The PER versus SNR for different packet lengths in the lab measurement.

DISCUSSION AND OUTLOOK

The first step towards outdoor measurements has been presented in this article. Tests have been conducted in a lab environment with the CVIS hardware platform using IEEE 802.11p for finding the PER versus SNR for different packet lengths at 6 Mbps. The two CVIS boxes were connected with a cable and a stepped power attenuator was used for reaching different SNR.

In a realistic VANET scenario there will be interference created by nodes within radio range of each other that are sending at the same time. Therefore, it is not enough to just have two nodes and measure the RSSI between them since the noise and the interference interact with the desired signal in different ways. The noise in a system is usually constant and is caused by the electrical circuitry of the receiving chipset. The interference, on the other hand, has the same structure as the desired signal as it comes from transmitters sending at the same time. Another difference between noise and interference is that the latter is also subject to fading, implying that the signal strength is varying, often over the packet duration. Concurrent transmissions in CSMA are caused by several nodes simultaneously sensing the wireless channel as well as randomized backoff times reaching zero at the same time. When the network load increases the concurrent channel access attempts also increase and can cause problem for the receivers. This has been pointed out in (7). Therefore, measurements using real hardware when two nodes are sending at the same time to one receiver are of utmost importance to find the PER versus SINR. However, there are some practical problems that must be solved first. The RSSI value is measured only in the preamble of the PHY header and not over the whole packet. Therefore, the two transmitting nodes must either start sending at exactly the same point in time (totally time synchronized) or a transmission schedule must be setup where the packets of one transmitter are longer than the others. Unfortunately, total time synchronization between the transmitters is not a realistic solution. The schedule solution requires that the carrier sensing performed by every node prior to transmission can be turned off to avoid that the backoff mechanism is invoked.

The next step is to solve the abovementioned problem with carrier sensing and setup a measurement with two transmitters and one receiver in the lab environment. When everything is up and running in the lab, outdoor field tests will be performed. The results from the outdoor measurements is then to be fed into a computer simulator complementing an already existing realistic channel model (3) that can model the radio wave propagation when vehicles communicate with each other in e.g., a highway scenario. This channel model is based on a channel sounding measurement campaign in various environments. The computer simulator can then be used to evaluate, e.g., the scalability of VANETs in a highway scenario to complement ongoing FOTs.

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