Evaluation of communication distance of broadcast messages in a vehicular ad-hoc network using IEEE 802.11p

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***Abstract*—Current research for vehicular communication is largely driven by the the allocation of 75MHz spectrum in the 5.9GHz band for Dedicate Short Range Communications (DSRC) in North America. The IEEE 802.11p Physical (PHY) layer and Medium Access Control (MAC) layer that is currently under standardization aim at communication distances of up to 1000m. In this paper we evaluate the maximum communication distance of an IEEE 802.11p vehicular ad-hoc network including mobility effects and multi-path propagation. Furthermore the communication distance for different path loss exponents is evaluated.**

***Index Terms*—DSRC, IEEE 802.11p, VANET**

I. Introduction

Research on vehicular communication got a major boost from the Federal Communications Commission (FCC) allocating 75 MHz spectrum at 5.9 GHz for Intelligent Transport System (ITS) applications in the US in October 1999.

Medium Access Control (MAC) protocols for vehicular communication are developed to support the most demanded applications like danger warning and toll collection. To enable these applications, the achievable communication range is a critical parameter. It decides the duration, a vehicle may communicate with a road side unit (RSU) or another vehicle. Moreover it is the critical measure for safety relevant communication as more distance translates into additional reaction time for the driver.

The wireless local area network (WLAN) based approach currently standardized by the IEEE 802.11p task group aims at communication distances of up to 1000m. Simple link budget calculations neglect the effects of the vehicular environment evolving from the multi path propagation and mobility effects.

In this paper we evaluate the maximum communication distance for different channel parameters using event-driven, stochastic simulation. Beside the IEEE 802.11p PHY and MAC, a two-ray channel model takes the special conditions of multi-path propagation into account. A mobility model emulates the realistic behavior of vehicles in the scenario.

II. IEEE 802.11p

The FCC petition for 5.9 GHz was launched in 1999 and the standardization work started in the ASTM group E17.51 based on IEEE 802.11a. In year 2002, the ASTM E2213-02 standard was approved and accepted as the basis for 5.9 GHz American Intelligent transport systems) ITS. The standard was reissued as ASTM 2213-03 in September 2003. The further standardization was transferred to the IEEE 802.11 working group. In September 2003 the study group (SG) for Wireless Access in Vehicular Environment (WAVE) met for the first time. In September 2004 the Project authorization request (PAR) was approved and the WAVE SG became Task Group (TG) "p". The TG completed the initial draft 1.0 in February 2006. The actual version 1.2 of the draft will be balloted on in November 2006. This paper refers to the information in this actual draft IEEE 802.11p-D1.2.

A. *Physical layer*

The PHY used for the simulation is the IEEE 802.11p OFDM PHY. It is a variation of the OFDM based IEEE 802.11a standard. The IEEE 802.11a PHY employs 64-subcarrier OFDM. 52 out of the 64 sub-carriers are used for actual transmission consisting of 48 data sub-carriers and 4 pilot sub-carriers. The pilot signals are used for tracing the frequency offset and phase noise. The short training symbols and long training symbols, which are located in the preamble at the beginning of every PHY data packet, are used for signal detection, coarse frequency offset estimation, time synchronization, and channel estimation. A guard time GI, is attached to each data OFDM symbol in order to eliminate the Inter Symbol Interference introduced by the multi-path propagation. In order to combat the fading channel, information bits are coded and interleaved before they are modulated on sub-carriers. IEEE 802.11p PHY takes exactly the same signal processing and specification from IEEE 802.11a except for the following changes:

1 Operating frequency bands for IEEE 802.11p are 5.9 GHz American ITS band. The 75 MHz are divided in seven 10 MHz channels and a safety margin of 5 MHz at the lower end of the band. The center channel is the control channel, on

which all safety relevant messages are broadcasted. The remaining channels are used as service channels, where lower priority communication is conducted after negotiation on the control channel As an option two adjacent service channels may be used as one 20 MHz channel. The European frequency regulation Conférence Européenne des Administrations des Postes et des Télécommunications (CEPT) is currently working on a similar frequency allocation.

2 In order to support larger communication range in vehicular environments, four classes of maximum allowable Effective Isotropic Radiated Power (EIRP) up to 44.8 dBm (30W) are defined in IEEE 802.11p. The largest value is reserved for use by approaching emergency vehicles. A typical value for safety relevant messages is 33 dBm.

3 To increase the tolerance for multi-path propagation effects of signal in vehicular environment, 10 MHz frequency bandwidth is used. As the result of reduced frequency bandwidth, all parameters in time domain for IEEE 802.11p is doubled comparing to the IEEE 802.11a PHY. On the one hand this reduces the effects of Doppler spread by having a smaller frequency bandwidth; on the other hand the doubled guard interval reduces inter-symbol interference caused by multi-path propagation.

4 As a result of the above the data rate of all PHY modes is halved.

B. MAC layer

Prioritized channel access in IEEE 802.11p uses the Enhanced distributed channel access (EDCA) mechanism originally provided by IEEE 802.11e. It includes listen before talk (LBT) and a random back-off. The back-off consists of a fixed and a random waiting time. The fixed waiting time is a number of "slots" given by the parameter AIFSN; a slot duration is 8µs. The random waiting time is also a number of slots, but the factor is drawn from a Contention Window (CW). The initial size of the CW is given by the factor CWmin. Each time, a transmission attempt fails, the CW size is doubled until reaching the size given by the parameter CWmax.

Prioritization is provided by using different channel access parameters for each packet priority. There are four available access categories originally defined for background (AC_BK), best effort (AC_BE), voice (AC_VO) and video (AC_VI) traffic. The parameter set used in IEEE 802.11p is shown in table 1:

In the high mobile environment the time interval, during which vehicles are in communication distance is very limited. To make optimal use of this short time period the communication overhead needs to be as low as possible. Thus no frame exchange on the wireless medium is needed before the actual data transmission. A Wireless Access in vehicular environments (WAVE) basic service set (BSS) is initiated by a provider station (STA) that transmits a WAVE service announcement frame (WSA) regularly. This management frame is similar to the beacon frame in ordinary IEEE 802.11 infrastructure BSSs but there are no restrictions on

TABLE I
EDCA PARAMETER SET

AC	CWmin	CWmax[a]	AIFSN
AC_BK	15	1023	9
AC_BE	7	15[2]	6
AC_VO	3	7	3
AC_VI	3	7	2

transmission intervals. There is no authentication and no association frame exchange needed to join a WBSS, it is an internal process of the joining STA. As the beacon frame is not used, the timing synchronization function (TSF) is not available. To achieve synchronization an external time reference like GPS has to be used.

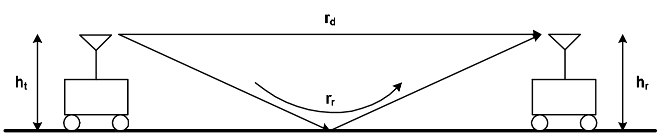
WAVE STAs use the clear channel assessment (CCA) busy fraction to determine the channel occupancy as base for congestion control mechanisms. The CCA busy fraction is the percentage of time, the PHY sensed the channel not being idle during a time interval.

III. CHANNEL MODEL

Multi-path propagation is the most important characteristic of the vehicular communication channel. The radio wave reaches the receiver via two or more paths. The effects are constructive or destructive interference and phase shifting of the signal. The fading of the channel can not be described by large scale fading alone – significant small scale fading occurs within distances of meters.

An approach to model multi-path propagation very detailed is ray-tracing, where each possible propagation path (up to a maximum number of reflections) is calculated. Unfortunately the calculation is very time consuming and needs to be repeated with every movement of transmitter, receiver or reflector. The large number of calculations make ray-tracing unusable for stochastic simulation.

A compromise between detail and calculation efficiency is to calculate two propagation paths, the direct path and one reflected path like shown in figure 1.



$$P_r = \frac{P_t}{(4\pi)^2 \left(\frac{d}{\lambda}\right)^{\gamma}} \left[1 + \eta^2 + 2\eta \cos\left(\frac{4\pi h^2}{d\lambda} \right) \right]$$

Figure 1 Two-ray channel model

The calculation is conducted for every combination of transmitter and receiver. A phase shift is applied to the reflected propagation path, depending on the material of the reflector. As the road is the main reflector in the vehicular environment, the reflection coefficient for asphalt is chosen. Beside the distance between transmitter and receiver, the wavelength, the reflection coefficient and the antenna height, the path-loss exponent “Gamma” is a parameter for the path-loss calculation. A Gamma value of 2.0 represents free space propagation, a value of 3.5 is a relatively lossy environment mainly found indoor. Based on the work in [1] the path loss exponent 2.4 for the scenario evaluated in this paper is selected.

A detailed description on the channel modeling and error model used for the simulation can be found in [2].

IV. Mobility model

The mobility model emulates the driver behavior in the scenario. Each vehicle has a preferred speed, depending on its type. The preferred speed is not necessarily the actual speed – each vehicle maintains a speed dependant safety distance to its predecessor. While the safety distance requirement is met, the vehicle accelerates up to its preferred speed. If accelerating to, or driving at the preferred speed is not possible, a change to the overtaking lane is considered. When distance checks to the front and rear view of both lanes, the current and the target lane, are passed, a lane change is conducted. When no lane change is possible, the vehicle de-accelerates until the safety distance requirement is met again, or the vehicle halts.

Vehicles leave the scenario at the border (different for both directions), new vehicles are inserted on the opposite side.

V. Scenario description

The scenario chosen for the evaluation is the highway scenario. Four highway lanes, two for each direction, are divided by a middle separator. The scenario setup is shown in figure 2. The length of the highway is 5km with up to 40 vehicles. Four different types of vehicles with a preferred speed between 60km/h and 180km/h are simulated.

Each vehicle transmits ten 150byte packets per second, resulting in a constant bit rate (CBR) of 12kbit/s. The packets are transmitted with the broadcast address, so each vehicle in communication range is a possible receiver. The message size is chosen for status messages, transmitted regularly by each vehicle, revealing its presence, so called “Hello” messages.

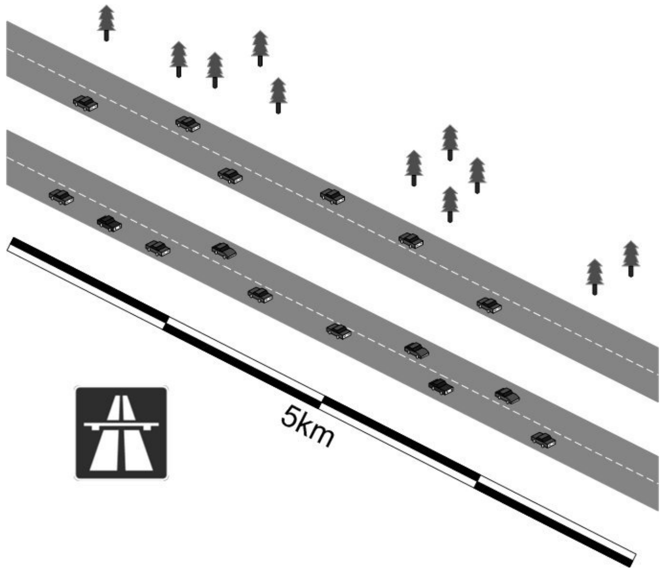


Figure 2 Highway scenario

The antenna height of the vehicles is set to 1.65m. The reflection coefficient of the reflected path in the 2-ray channel model is -0.7 (asphalt).

On the physical layer the most robust PHY mode is chosen (Binary Phase Shift Keying with 50% redundancy, BPSK1/2). The transmission power is 33dBm (2W). Omni-directional antennas are used, so no antenna gain is involved. The center frequency is 5.9GHz with a channel bandwidth of 10MHz.

In the MAC layer, the second-highest access category (AC_VI, see tabular 1) is chosen for the prioritized channel access, as the transmitted packets shall be status messages, not warning messages.

The IEEE 802.11p protocol stack, the channel and mobility model were implemented in our event-driven stochastic protocol simulator Wireless Access Radio Protocol 2 (WARP2). The simulator has been used in many publications, diploma and PhD thesis, as well as in the standardization of IEEE 802.11e (Quality of Service), IEEE 802.11p (Wireless access in vehicular environments) and IEEE 802.11s (Mesh networks). It features a very detailed MAC implementation and a realistic interference modeling.

VI. Simulation results

The parameter evaluated during the simulation is the probability for successful communication. The successful communication includes more than just the packet reception itself. Thus it is different from the packet error rate (PER). For a successful communication the following two conditions need to be fulfilled:

1 A receiver is within communication distance of the transmitter

2 The packet is received successfully

The probability of a receiver being in communication range of the transmitter is influenced by the mobility model, vehicle density and the scenario size. The successful reception of the packet depends on the path-loss coefficient and packet collisions.

The parameter for the path-loss (Gamma) is varied starting from 2.0 representing free field propagation up to 3.5 which resembles in-door propagation in steps of 0.1. All simulation parameters are listed in section V.

The results are shown in figure 3 as complementary cumulative distribution function (CCDF) of the probability for successful communication per path-loss exponent. Figure 4 is a magnification for the smaller distances. The curve on the right shows the distribution for the gamma value of 2.0 (free space propagation). From right to left the value for the pass-loss exponent increases by 0.1 per curve up to 3.5. The curve for the path-loss exponent 2.4 (see section 3) is highlighted.

The simulation results show, that the path-loss exponent of 2.4 leads to communication ranges smaller than the envisioned 1000m. 90% of the successful communications take place at 750m and less. Only 1% of the successful communications are conducted at 900m.

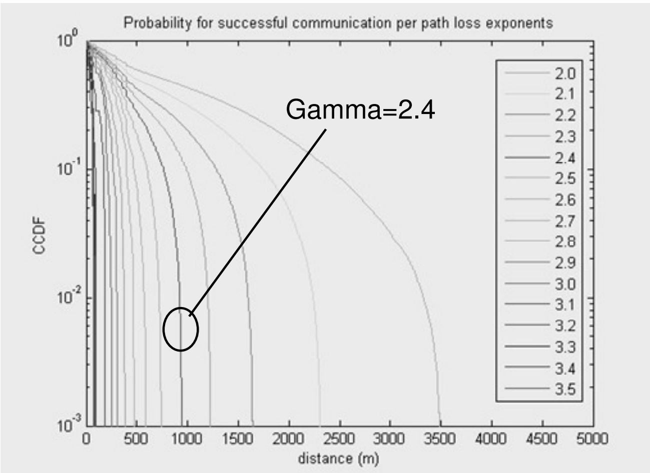


Figure 3 Probability for successful communication per path loss exponent

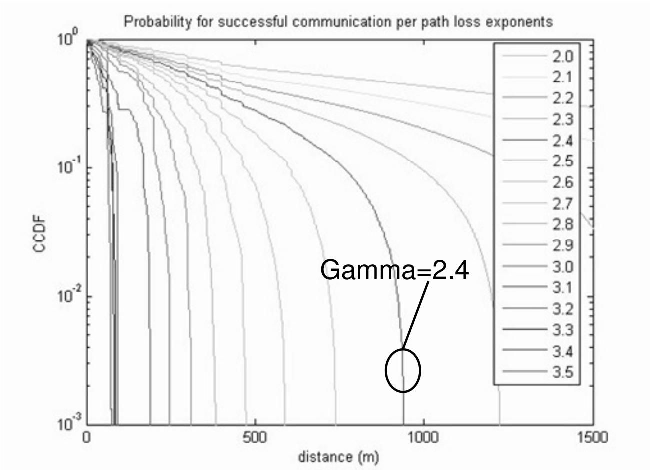


Figure 4 Probability for successful communication per path loss exponent, 1000m focus

VII. Conclusion

In this paper, we evaluated the maximum communication distance for IEEE 802.11p transceivers in a highway scenario. A large difference between free space propagation (path loss exponent 2.0) and the vehicular environment (path loss exponent 2.4) occurs.

The envisioned communication range of 1000m in the IEEE 802.11p project authorization request (PAR) can not be reached with 2W EIRP in the investigated highway scenario. 90% of the successful communications were conducted at a distance of less than 750m. For a vehicle approaching a road side unit with 120km/h a maximum communication time of 22,5s is an upper boundary to be considered for efficient vehicular communication protocols. Larger communication distances may be achieved via multi-hop car-to-car communication.

In the next step we will investigate the performance of IEEE 802.11p for rear end collision warning applications.

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