Estimation of Doppler Shift for IEEE 802.11g Standard

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Abstract

The common problem of the OFDM systems is the high sensitivity to frequency offset caused by tuning oscillator instabilities and Doppler shifts induced by the channel. Time variances of the channel during one OFDM symbol interval destroy the orthogonality of different subcarriers and generate power leakage among subcarriers, known as Inter-Carrier Interference (ICI). ICI in OFDM systems degrades the performance of both symbol detection and channel estimation. ICI produce phase noises which increase error vector magnitude (EVM) for conventional digital modulation methods such as phase-shift keying (PSK) and quadrature-amplitude modulation (QAM). The main focuses of this research are theoretically and practically evaluate the wireless local area network (WLAN) with Institute of Electrical and Electronics Engineers (IEEE) 802.11g standard in mobile environment such as vehicular to infrastructure (V2I) from Doppler Effect aspect.

1 Introduction

Short-range vehicle-roadside or V2I communication is expected to be a part of the future intelligent transportation system (ITS) in order to increase the safety of the roads and efficiency of the traffic. Therefore, investigation on proper communication for ITS is increasing. Today, the IEEE 802.11g standard for high data rate wireless networks is widespread and costs effective. Extension of this standard could be a part of V2I communication technology. The IEEE 802.11g is Orthogonal Frequency Division Multiplexing (OFDM) based standard. In OFDM, multiple frequency channels, known as sub-carriers, are orthogonal to each other. Well known problem of OFDM is sensitivity to frequency offset between the transmitted and received signals, which may be caused by Doppler shift in the channel, or by the difference between the transmitter and receiver local oscillator frequencies. Carrier frequency offset causes loss of orthogonality between sub-carriers. Signals which are transmitted on each carrier are not depended from each other. That leads to inter-carrier interference (ICI). Some problems such as throughput, coverage range, Doppler shift, response times have to be solved before wireless vehicle-roadside infrastructure can be used on roads. In this paper an analysis of frequency offset caused by Doppler shift over experimental IEEE 802.11g wireless network is proposed.

2 802.11g-based Wireless LAN

Wireless Local Area Networks with IEEE 802.11g standard are most widespread today. 802.11g standard uses OFDM and Complementary Code Keying (CCK) to support higher raw data rate "over the air" (up to 54 Mbps) and rate in MAC Layer (up to 25 Mbps). OFDM is multi-carrier modulation which converts single high-rate bit stream to low-rate 64 parallel bit stream. Each sub-carrier can be modulated by binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), 16-symbol quadrature amplitude modulation (16QAM), 64-symbol quadrature amplitude modulation (64QAM). To achieve high bandwidth efficiency, the spectrum of the sub-carriers with frequency spacing has to be closely spaced and overlapped. The OFDM symbols are generated using IFFT. Practically, OFDM symbol is sensitive to frequency offset [4]. On the receive side, a frequency offset correction scheme has to be used in addition. For 802.11g standard a receiver frequency tolerance which is equal with ± 60300 Hz is defined.

3 Doppler Shift

Doppler shift can cause significant problems if the transmission technique is sensitive to carrier frequency offsets or if the relative speed is too high. When an electromagnetic wave source and the receiver are moving relatively one to another, the received signal frequency will not be the same as the source signal frequency. When they are moving toward each other the frequency of the received signal is higher than the source frequency, but when they are moving from each other the frequency of the received signal is lower than the source frequency. This occurrence is called the Doppler shift. The amount of the Doppler shift depends on relative motion between source and receiver and on the speed of wave propagation. Maximal Doppler shift for frequency is calculated according to the formula:

$$f_d = \frac{v_r \cdot f_c}{c} \cos \alpha \tag{1}$$

where f_c is source frequency, v_r is the speed difference between objects, c is the speed of light ($3 \cdot 10^8$ m/s), and $\alpha \in [0, \pi]$ is the angle of the velocity vector. Our aim is to get maximal f_d which happens when $\alpha \to 0$. (1) can be changed to

$$f_d = \frac{v_r \cdot f_c}{3.6 \cdot 3 \cdot 10^8} \tag{2}$$

Values of f_d for 2.4 GHz carrier and various speeds are listed in Table 1. On the speed range from 10 km/h to 120 km/h the Doppler shift is from 20 Hz to 300 Hz.

V(km/h)	10	20	30	40	50	60	70	80	90	100	110	120
f_d(Hz)	22	44	66.7	88.9	111	133	155.6	177.8	200	222	244	266.7

Tab. 1: *Doppler shift for various speeds*

$$\mu = \frac{f_d}{f_c} \tag{3}$$

The relative Doppler shift (μ) is about 10^{-8} to 10^{-7}, which is very small. The fact that all subcarrier frequencies changes identically destroys the orthogonality between subcarriers [5] and generate power leakage among the subcarriers, known as ICI. Theoretical influence of maximal Doppler shift on 802.11g standard on the speed of vehicle from 10 till 120 km/h is very low. In this case it is possible analytically to determine the speed (v_r) of the vehicle when the affect of Doppler shift can influence on the signal:

$$v_r = \frac{f_d \cdot 3.6 \cdot 3 \cdot 10^8}{f_c} \tag{4}$$

4 Testing Environment and results

The goal of practical test was to investigate the possibility of 802.11g standard use in V2I practical environment from Doppler shift aspect. For assessing the quality of the OFDM signals we have measured error vector magnitude (EVM).

This measurement gives an overall view of quality of the modulated signal, which in turn gives a sense of how well the receiver would be able to receive and interpret the signal. This information is closely related to the physics layer of the system and gives a complete picture of the channel distortion. EVM can be more useful to the microwave engineer because it contains information about both amplitude and phase errors of the signal [2]. EVM is a measure for the difference between the theoretical wave and modified version of the measured waveform. The measured waveform is modified by first passing it through a specified receiver measuring filter. The EVM result is defined as the square root of the ratio of the mean error vector power to the mean reference signal power expressed as a percentage or dB. Mathematically, the error vector e can be written as

$$\underline{e} = \underline{w} - \underline{v} \tag{5}$$

Where $\underline{w}$ is the modified measured signal and $\underline{v}$ the ideal transmitted signal. The error vector $\underline{e}$ for a received symbol is graphically represented in figure 1.

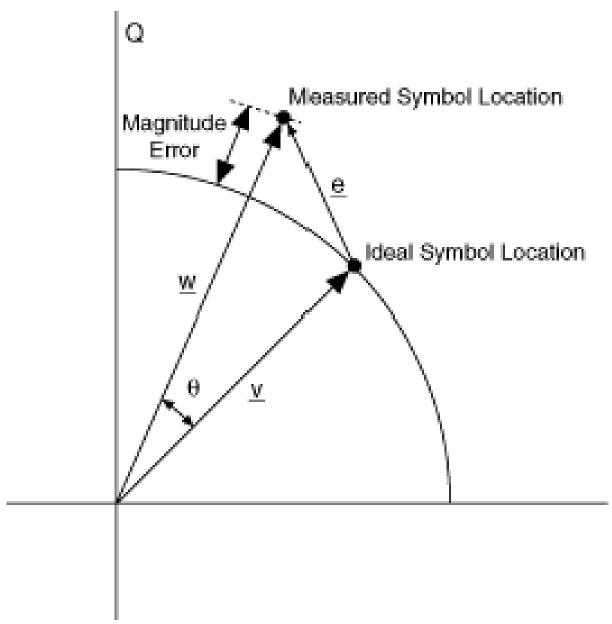

Fig. 1: *Representation of Error Vector*

EVM can be defined as

$$\sqrt{\frac{E[|\underline{e}|^2]}{E[|\underline{v}|^2]}} \tag{6}$$

The wireless link is highly influenced by their surrounding environment. Therefore the test bed was chosen carefully with no obstacle in the line of sight and no interfering wireless network in the neighborhood. For the experiments the airfield "Rumbula" in Riga city, Latvia (Fig. 2) was chosen.

Fig. 2: *Testing Location at the Airfield of Rumbula*

The nearest obstacle was 300-400 m away from the airfield surface and no other wireless networks could be detected. Additionally this place was chosen for vehicle safety reasons, because during the experiments the vehicle had to reach the speed of 120 km/h.

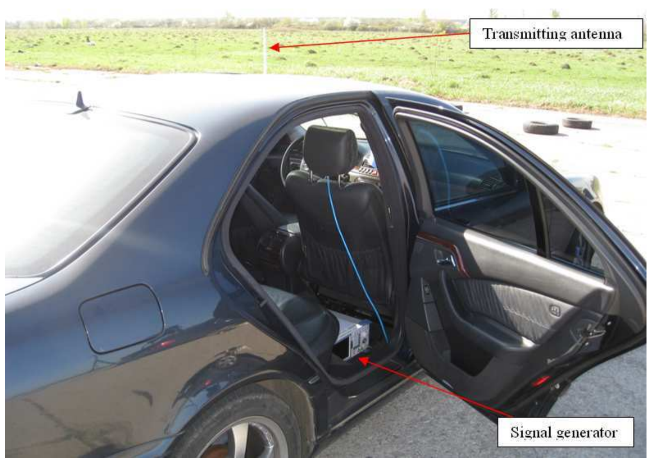

Fig. 3: *Signal transmitting side*

For the experimental signal generation in the test bed the vector signal generator R&S®SMBV100A was used. It was set on a moving vehicle (Fig. 3). Signal analyzer R&S FSV-K91n was used for wireless signal estimation (Fig. 4).

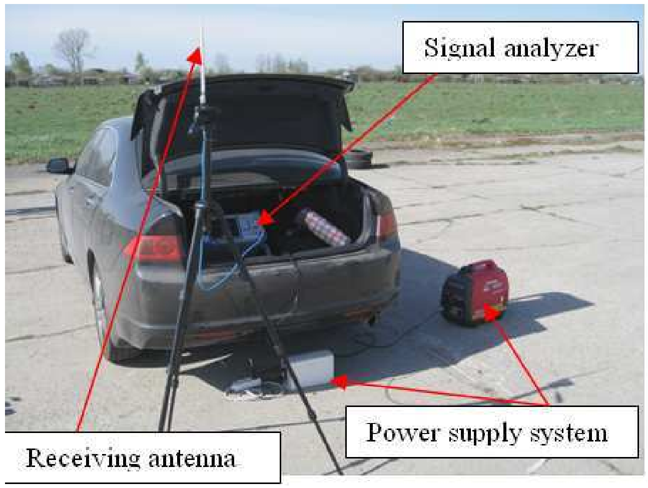

Fig. 4: *Signal receiving side*

Signal generator power supply was established by UPS APC 1000VA, but signal analyzer power supply was established by 2kW power generator with APC UPS (Fig. 4).

The focus was to set the best link with the highest signal transfer speed for OFDM 16-QAM (24Mbps) and for OFDM 64-QAM (54Mps) and optimal line of sight distance between receiving and transmitting sides (about 200 meters). For the experiment first channel (2.412 GHz) with signal output level +15 dBm was used. For the wireless measurements the sequence at fixed link-layer data rate 24 Mbps and 54 Mbps in 802.11g-only mode and with no automatic data rate adaptation was performed. In order to get right movement speed shown in table 1 for each measurement the moving vehicle with the signal generator was equipped with automatically controllable speed limiter.

Figures 5 and 6 shows data that was received on the Rohde&Schwarz FSV-K91n signal analyzer when vehicle speed was 20 km/h.

The Figure 5 or result summary list presents the overall measurement results and provides limit checking for result values in accordance with the 802.11g standard [1]. Result values which are within the limit as specified by the standard are displayed in green. Result values which are outside of the limits specified by the standard are displayed in red (not present in figure). Results which have no limits specified by the standard are displayed in white (bold). Limit values which are displayed in white (not bold) can be modified. The results displayed in this list are for the entire measurement. If a specific number of bursts have been requested which requires more than one sweep, the result summary list is updated at the end of each sweep. The number of bursts measured and

Fig. 5: *EVM estimation example on the Rohde&Schwarz FSV-K91n signal analyzer*

the number of bursts requested are displayed to show the progress through the measurement. The Min / Mean / Max columns show the minimum, mean or maximum values of the burst results.

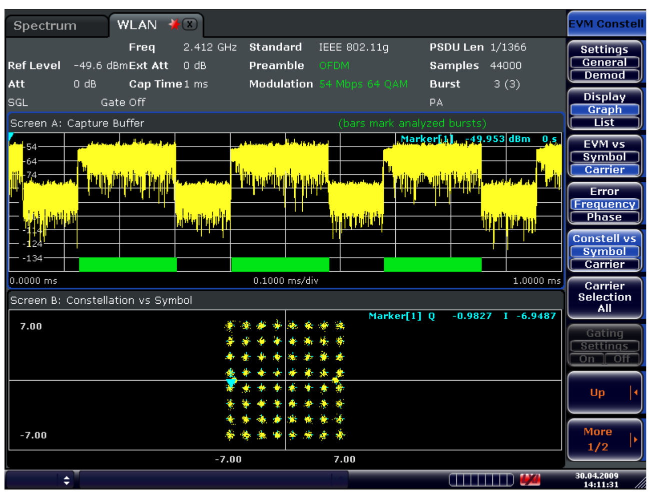

Fig. 6: *Signal constellation example on the R&S FSV-K91n signal analyzer*

Figure 6 is divided in two screens - the Magnitude Capture Buffer for all IQ measurements and the Constellation versus Symbol. The Magnitude Capture Buffer display shows the complete range of captured data for the last sweep. All analyzed bursts are identified with a green bar at the bottom of the Magnitude Capture Buffer display. The Constellation versus Symbol result screen shows the in-phase and quadrature phase results over the full range of the measured input data.

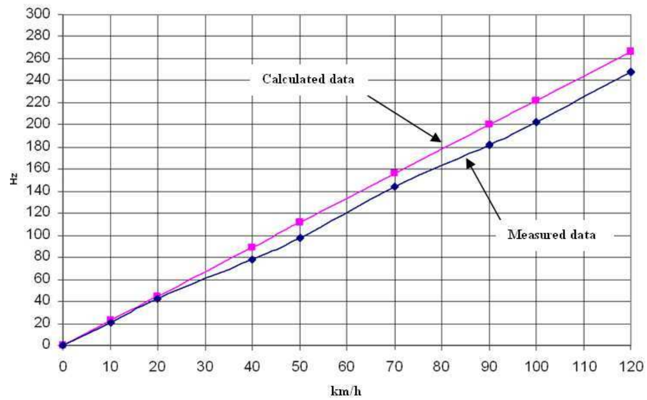

Fig. 7: *Doppler shift diagrams*

When all necessary measurements were made it is possible to analyze experimental data. Theoretical (red line) and practical (blue line) of Doppler shift are shown in Fig. 7. The difference between theoretical and practical data is small.

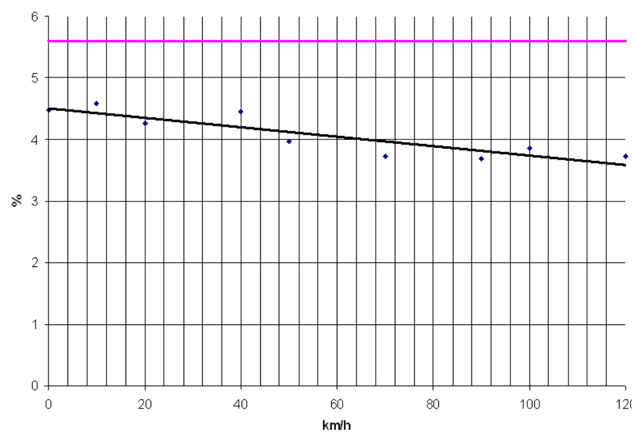

Fig. 8: *EVM (%) dependence from the vehicle speed and linear trend line*

In OFDM link sub-carriers are perfectly orthogonal only if transmitter and receiver use exactly the same frequencies. Any frequency offsets in Inter-Carrier Interference (ICI) [5] could increase EVM. The 802.11g standard have define EVM limits for each data rate (e.g. 54 Mbps EVM $<$ 5.6%, 24Mbps EVM $<$ 15.85%). Under the red line on figures 8 and 9 a field is shown that can satisfy the necessary link establishment to transfer correct data in wireless network. Figure 8 shows dependence of EVM from the vehicle speed on 54Mbps data speed with 64-QAM. Average EVM on 10 km/h was 4.48% and on 120 km/h was 3.73%. The linear trend in figure 7 shows small EVM improvement on higher vehicle speed.

Figure 9 shows dependence of EVM from the vehicle speed on 24 Mbps 16-QAM. In this case EVM limit according to standard was three times greater than experimental EVM. Average EVM on 10 km/h was 4.57% and on 120 km/h was 4.03%.

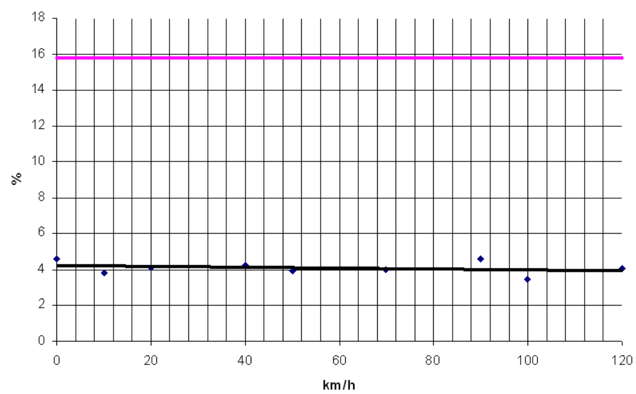

Fig. 9: *EVM (%) dependence from vehicle speed and linear trend line*

5 Conclusion

The main task of this research was to evaluate the Doppler shift impact on the 802.11 g V2I wireless mobile network. The main task was to prove that IEEE 802.11 g equipment with OFDM technology is sensitive against frequency offset [3] that caused power leakage between OFDM subcarriers on different vehicle speeds. This task was fulfilled completely.

After the summarizing of the theoretical and practical results fallowing conclusions came by: Doppler Effect influence on wireless network based on WLAN OFDM with IEEE 802.11 g standard technology were observed; Gained theoretical and practical results show that WLAN OFDM with IEEE 802.11g technology is consistent against channel time dispersion which can appear while vehicle is moving.

References

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