Wireless Communications for Intelligent Transportation Systems

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Abstract

In this contribution an iterative technique for channel estimation using soft-information feedback for intelligent transportation systems (ITS) communications is presented. We discuss the results obtained from numeric simulations using this technique enabling a bit error rate below 10^{-3} in an IEEE 802.11p system for users moving with a velocity larger than 50km/h = 13.8m/s in a non-line of sight situation and an E_b/N_0=10dB. Furthermore, we validate the channel estimator with real data collected during transmission experiments on the road.

Keywords:

Channel estimation, vehicular communications, iterative, IEEE 802.11p

I – Introduction

Vehicular communications are aided to enable reliable data transmission in order to reduce the accident rate on the road as well as driving more intelligently and therefore enviromentally friendly. Due to the challenging propagation conditions in vehicular scenarios, the IEEE 802.11p conventional receiver algorithms are not able to deliver good performance [1] in non-line of sight situations for velocities larger than 50km/h=13.8m/s. Therefore, new transceiver techniques must be investigated that enable more reliable and robust system performance for vehicular communications.

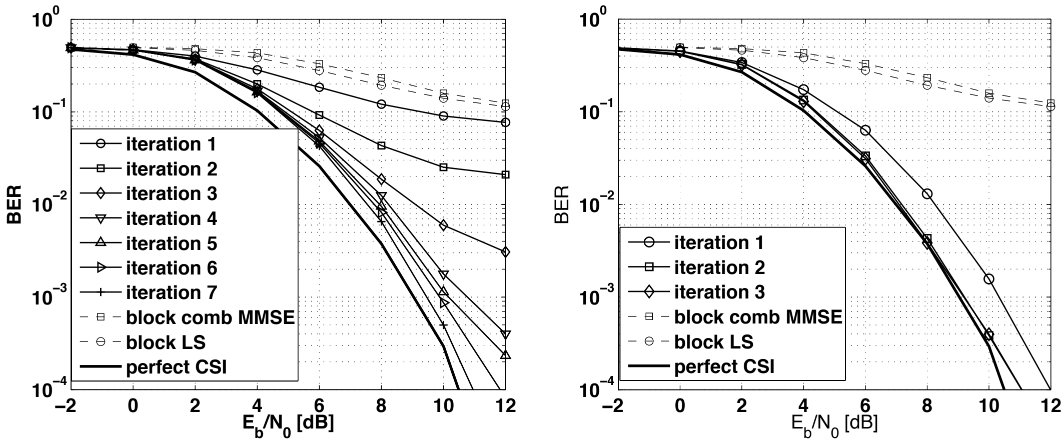
The work presented in this publication was carried out within the project Robust and Distributed Safety-Improved Traffic Telematics (ROADSAFE), a scientific cooperation between FTW, ASFINAG, Kapsch TrafficCom, Fluidtime, and TU Wien, to improve vehicular communication systems based on IEEE 802.11p.

Contributions of the paper

In this paper we review the performance of a two-dimensional reduced-rank channel estimator which outperforms conventional techniques in terms of bit error rate (BER). Furthermore, a backward compatible pilot pattern enhancement for IEEE 802.11p is proposed. Both, allow for a reduced channel estimation error and enhanced convergence speed of the BER towards the one achievable with perfect channel state information (CSI). Results are shown for numeric simulations as well as for data collected through transmission experiments on the road.

II – Channel Estimation for Vehicular Communications

Conventional channel estimators cannot cope with the harsh conditions of the vehicular fading channel. Soft-information based iterative algorithms help to improve the receiver performance since the channel estimate obtained after each iteration is more accurate and reliable. A further improvement can be obtained by using a reduced rank two-dimensional channel estimation technique based on subspace projection of the channel coefficients adapted to the IEEE 802.11p pilot pattern [2]. The used subspace can be represented by the discrete prolate spheroidal sequences (DPSS). The achieved BER results can converge to perfect CSI, overcoming the error floor obtained with conventional techniques [1,3,4].



(a) BER (E_b/N_0) without post-amble (b) BER (E_b/N_0) with post-amble

Figure 1 – BER for 200 byte packet length, NLOS and driving velocity of 100 km/h.

III – Numerical Simulation Results

Figure 1 (a) shows the BER curves for a typical non-line of sight (NLOS) situation in a vehicle-to-infrastructure (V2I) link. The results are obtained with an IEEE 802.11p compliant MATLAB simulator with a packet length of 200 bytes and considering a vehicle moving at a speed of 100 km/h. The convergence of the BER to the perfect CSI is achieved after 5 iterations. Noteworthy is the improvement achieved with respect to conventional channel estimation techniques (block-based least squares (LS) and block-comb minimum mean square error (MMSE) are shown in the plot for comparison).

One of the big challenges of the used pilot pattern in 802.11p is the difficulty to exploite the pilot symbols for estimating the time-variability of the channel. By using fed back soft information iteratively, one can achieve good results at the expenses of an increased receiver complexity (each iteration adds complexity).

We propose a backward compatible solution to address the complexity issue of iterative channel estimation, as described in detail in [2]. By adding an extra OFDM pilot symbol at the end of the frame, called post-amble, the channel estimate obtained after the first iteration is already performing well, and the iterative algorithm converges much faster, as shown in Fig. 1 (b).

The DPSS-based soft iterative channel estimation technique with and without post-amble has also been evaluated using the non-stationary channel model [1,5] with consistent results. In Fig. 2 we show the BER performance for iterations 1 and 3 using both approaches in a V2I link, where the OBU (OnBoard Unit) drives at 100 km/h. The red curves show the BER without exploiting the post-amble and in blue are the ones with post-amble. The black solid line represents the BER for perfect CSI. In this plot, we assume a given E_b/N_0 of 16 dB when OBU and RSU (RoadSide Unit) are separated a distance of 1 m. When the OBU moves away from the RSU, the E_b/N_0 decreases as indicated in Fig. 2.

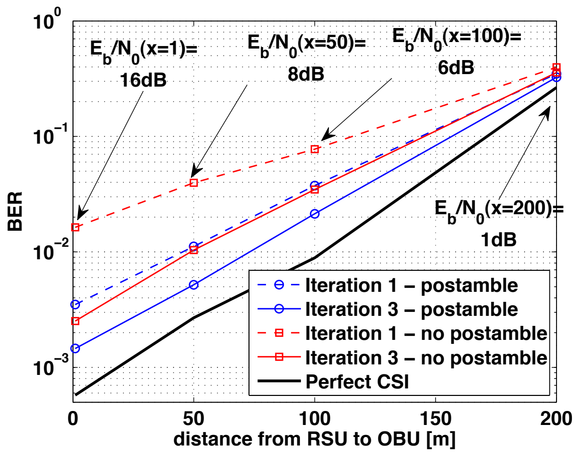


Figure 2 - BER in a V2I link assuming a E_b/N_0 = 16 dB at a distance x = 1 m.

Noteworthy is that the performance of the receiver with post-amble achieves after one iteration the same result as the receiver without post-amble after three iterations. Furthermore, after three iterations considering the post-amble, we obtain results close to perfect CSI.

IV – Empirical Results

The data used in this investigation were recorded during the measurements campaigns carried out in 2011 within the project ROADSAFE. An IEEE 802.11p standard compliant frame was sent, received, and stored. The measured scenarios include vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication links.

The raw measurements correspond to the oversampled baseband signal. They include the received frames and also noise sections. In order to properly process each individual frame, it is necessary to determine the sample where the frame starts, and afterwards subsample the raw signal in order to extract the actual received frames. The frame is composed out of a short training sequence, followed by a long training sequence (called here PREAMBLE consisting of 2 OFDM symbols) and a SIGNAL field (1 OFDM symbol) with encoded information about the DATA (variable number of OFDM symbols depending on the frame length), which is appended to the frame. Figure 3 shows the frame structure as defined in the IEEE 802.11p standard [8].

IV – A. Measurement Preprocessing

The raw data is preprocessed to obtain the frame start and to compensate an eventual frequency offset, which is expected to be constant throughout the entire frame. Then, the set of time synchronized and frequency compensated frames are processed as described below.

Timing Synchronization and Frequency Offset Compensation

We use the algortihm presented in [6] for timing synchronization and frequency offset estimation, which is based on the autocorrelation of the received training sequence. On the one hand, using this algorithm, the frame start is correctly detected. On the other hand, the results delivered for the frequency offset were unreliable. In order to overcome this problem, we empirically determined the frequency offset based on the first results obtained using [6], and set it to a constant value.

Signal to Noise Ratio (SNR) Estimation

In order to use certain channel estimation and equalization techniques, it is required to have an estimate of the SNR. We use the technique described in [7] to estimate an SNR value for each frame. The noise power is obtained by equalizing the symbols in the PREAMBLE and SIGNAL field, where we assume that the channel is time invariant. This is a reasonable assumption because of the short duration of the PREAMBLE+SIGNAL field that encompasses just 3 OFDM symbols long.

The signal and the noise power in the OFDM packets cannot be separated and therefore they are estimated together from the second order moment of the data symbols. For this purpose, we assume that the noise is independent and identically distributed additive white Gaussian noise.

Processing and Analysis of the OFDM Frame

The frame processing is done in a two-step approach. First, only the SIGNAL field OFDM symbol goes through the receiver chain. The SIGNAL field is composed by 24 BPSK symbols encoded with a coding rate equal to 1/2, which ensures a robust detection. The correctly decoded SIGNAL field delivers information regarding the RATE and the LENGTH of the DATA field, (see Fig. 3 for a detailed view of the frame and the SIGNAL field contents). The field RATE determines the modulation alphabet and the coding rate employed for the data OFDM symbols in the frame. The field LENGTH indicates the number of data bytes sent within the frame.

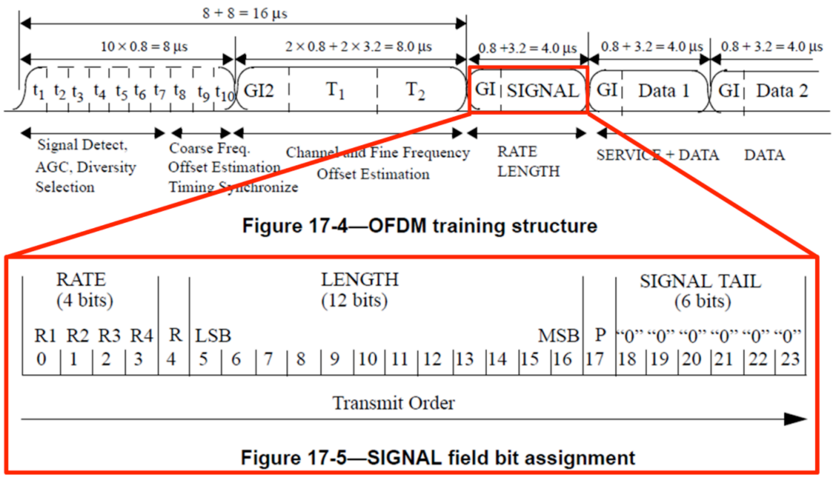


Figure 3. IEEE 802.11p frame structure and details of SIGNAL OFDM symbol

If the RATE and LENGTH fields contain feasible values according to [8], and besides that, the parity bit is correct and the tail bits are all zero, then we declare a *"SIGNAL SUCCESS"*.

If a *"SIGNAL SUCCESS"* was declared, the frame is further processed, otherwise it is discarded. First, a new SNR estimation is performed, now using the whole frame. Afterwards, the frame is processed by the receiver chain and finally the whole frame is submitted to the cyclic redundancy check (CRC). If the CRC is correct, we declare *"FRAME SUCCESS"*.

IV – B. Performance Comparison

In order to assess the performance of the previously described DPSS-based channel estimator, we use real measured data. We consider a 3000 frames long data file. The measurement was performed between two vehicles (V2V) under NLOS conditions. The two vehicles were driving on the highway in the same direction with a relative speed of 30 km/h and a further vehicle was obstructing the LOS between them.

We use a block least squares (B-LS) channel estimaton for decoding the SIGNAL field due to its reduced complexity and the fact that the channel remains almost time-invariant during the three first OFDM symbols of the frame [1].

We use different channel estimation techniques described in [1] in order to compare their performance with the one described in this publication. The equalization is done with an MMSE equalizer.

The different used channel estimators are:

- CLS-linear: Comb-based channel esitmator technique. It first estimates the comb pilots using a LS technique and then interpolates the channel coefficients using linear interpolation.
- CLS-spline: Comb-based channel esitmator technique. It is defined as the CLS-linear but it performs a spline interpolation instead.
- BC-MMSE1: Block-comb based channel estimator technique. It first estimates the channel coefficients at the pilot positions using a LS technique, and then applies a linear MMSE filter in the time domain. The linear MMSE filter used in BC-MMSE1 assumes a channel auto-correlation function from Clarke's model (NLOS).
- BC-MMSE2: Block-comb based channel estimator technique. It works as BC-MMSE1, but the channel auto-correlation function used for filtering is estimated from the comb pilots.
- DPSS-based: As described in this publication, we apply it using a single iteration.

Table I shows the *"SIGNAL SUCCESS"* and the *"FRAME SUCCESS"* obtained using different channel estimators listed by increasing frame success ratio (Number of frame success / Number of transmitted frames).

Channel estimator	SIGNAL SUCCESS	FRAME SUCCESS	Success ratio
CL-spline	2634	976	32.53 %
CL-linear	2634	1307	43.57 %
BC-MMSE2	2634	1525	50.83 %
BC-MMSE1	2634	1788	59.60 %
DPSS-based*	2634	1921	64.03 %
DPSS-based**	2634	2105	70.17 %

* Using just 2 basis functions in time and 19 in frequency

** Using an adaptive optimal number of basis functions

Table I. Results applying different channel estimatiors on measured vehicular data

The results obtained with the DPSS-based channel estimator outperform the conventional channel estimation techniques. We consider two cases for the DPSS-based channel estimation: DPSS-based* uses a fixed number of basis functions for estimation, namely 2 in the time domain and 19 in the frequency domain; DPSS-based** is an improved version of the same estimator where the number of basis functions is chosen adaptatively depending on the SNR estimated for every frame. With the improvement we correctly decode almost 200 frames more.

In general, the results improve as the complexity of the channel estimation increases. Noteworthy is that the results of BC-MMSE1 are slightly better than using BC-MMSE2. Both BC-MMSE estimators depend on the auto-correlation function of the channel. The

BC-MMSE1 assumes a known shape based on the Clarke's spectrum, and the BC-MMSE2 estimates the autocorrelation function from the four comb-pilot subcarriers. Clearly, when knowing the relative speed of the car, one can get a better autocorrelation matrix using the known shape (BC-MMSE1). However, noisy estimates of the covariance function, as used for BC-MMSE2, lead to reduced filter performance.

Figure 4 presents the cumulative *"FRAME SUCCESS"* and the estimated SNR over the 3000 frames for two different channel estimators. On the one hand, when the SIGNAL field is correctly decoded, the SNR is estimated using all OFDM symbols in the frame. On the other hand, if the SIGNAL field is not successfully decoded, the SNR estimation is obtained from the two preamble OFDM symbols and the SIGNAL OFDM symbol.

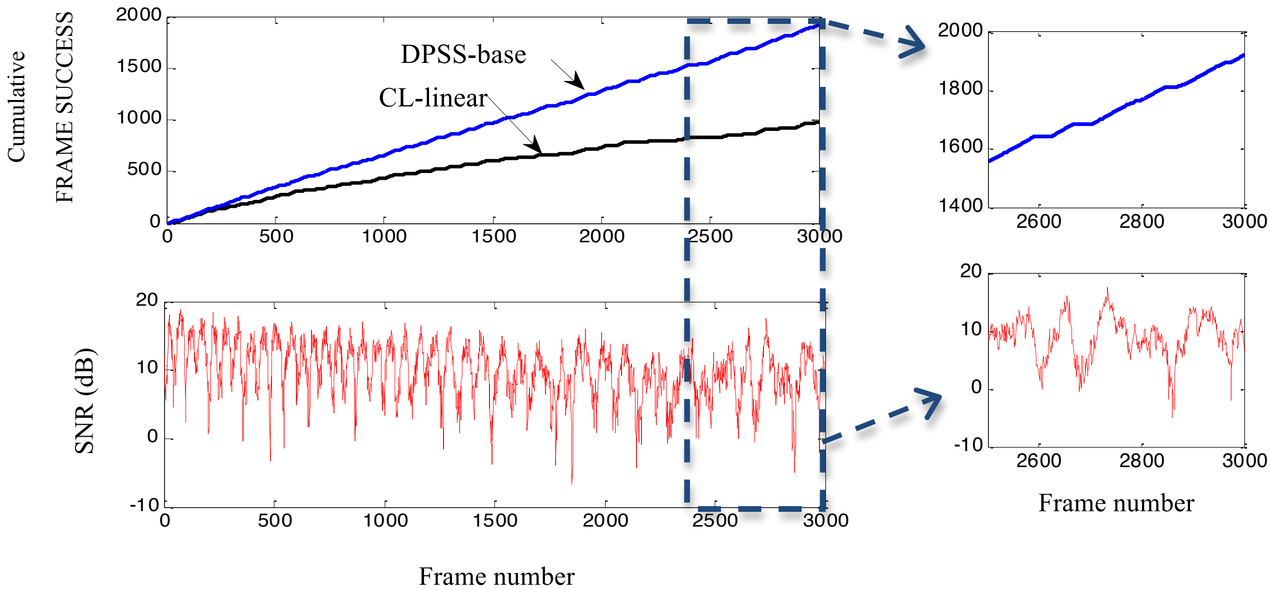


Figure 4. Cumulative SIGNAL and CRC success (upper plot), and SNR (lower plot) over 3000 frames

In order to analyze in detail the results depicted in Fig. 4, we zoom in the last 500 frames shown on the right hand side in Fig. 4. We can see that when the SNR is low, there are no *"FRAME SUCCESS"*, and as a result, the cumulative *"FRAME SUCCESS"* is a flat region.

V – Conclusions

In this paper we reviewed a new channel estimation technique for IEEE 802.11p communication systems, based on an iterative reduced rank two-dimensional channel estimation technique using a subspace projection of the channel coefficients adapted to the IEEE 802.11p pilot pattern. For the subspace projection we used the discrete prolate spheroidal sequences (DPSS). We have shown that the bit error rate results obtained in numerical simulations converge to the one with perfect channel state information iteratively. Furthermore, by using a backward compatible postamble for the IEEE 802.11p standard we can enhance the convergence speed. We also presented first results on the evaluation of the receiver algorithms developed during the ROADSAFE project with real measured data, namely from a vehicle-to-vehicle non-line of sight measurement. We have observed that the channel is strongly time- and frequency-selectivity. We could prove that the DPSS-based channel estimation outperforms the conventional techniques and achieves 70% correctly decoded frames already after the the first iteration.

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