On Channel Estimation for 802.11p in Highly Time-Varying Vehicular Channels

Keerthi Kumar Nagalapur, Fredrik Brännström, and Erik G. Ström
Chalmers University of Technology, Sweden

Nov. 11, 2014
Vehicular channels

- Scenario specific
- Highly time-varying
- Coherence time of less than 200 µs and coherence bandwidth of less than 200 kHz are reported in vehicular channel measurements[1]

802.11p OFDM frame
802.11p OFDM frame
Previous work

- Add additional training symbols periodically in the frame by proposing a change in PHY layer
- Channel estimation using decision feed-back
- Iterative channel estimation using decision feed-back (postamble) [1]

Our contribution

- A method to introduce complementing pilots into 802.11p frame in layers above MAC and PHY
- Backward compatible with an 802.11p compliant receiver (with an additional requirement at the receiver upper layers)
- Propose a receiver configuration that makes use of the complementing pilots
Flow of data to the PHY layer

<table>
<thead>
<tr>
<th>MAC:</th>
<th>Header</th>
<th>Data</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS:</td>
<td>SERVICE</td>
<td>Header</td>
<td>Data</td>
</tr>
</tbody>
</table>
Flow of data to the PHY layer

Pilot bits multiplexed with the data

MAC:
- Header
- Pilot bits
- CRC

PHY:
- SERVICE
- Header
- Pilot bits
- CRC
- Tail+Pad
802.11p transmitter

Convolutional encoder with a memory of 6-bits

Scrambler → Encoder → Interleaver → Mapper → S/P → IDFT
802.11p transmitter

Terminated in a known state

Scrambler → Encoder → Interleaver → Mapper → S/P → IDFT

[...d d t_1 t_2 t_3 t_4 t_5 t_6 p_1 p_2 ... p_k d d]
802.11p transmitter

Pseudo randomly initialized for every frame

Terminated in a known state

[...d'd't'_1t'_2t'_3t'_4t'_5t'_6p'_1p'_2... p'_k d'd'...]

[...d d t_1 t_2 t_3 t_4 t_5 t_6 p_1 p_2 ... p_k d d]
802.11p transmitter

The initial scrambler state is recovered at the receiver

Terminated in a known state

[...d’d’t_1’t_2’t_3’t_4’t_5’t_6’p_1’p_2’... p_k’d’d’...]

Pilots

[...d d t_1 t_2 t_3 t_4 t_5 t_6 p_1 p_2 ... p_k d d]
Modified 802.11p frame

Subcarriers $k$

OFDM symbol $m$

- $M_S$
- $M_P$
- $M_A$
- $M_E$

- Pilots
- SIGNAL
- DATA
Blockwise channel estimation and decoding
LMMSE channel estimator

\[ \hat{h} = R_1 R_2 + \sigma^2 (PP^*)^{-1})^{-1} \hat{h}_P \]

\( \hat{h}_P \) - Least square channel estimates at pilot positions

\( P \) - Matrix with pilot symbols in the diagonal

\( R_1, R_2 \) - Cross and auto correlation matrices obtained using the theoretical correlation functions in time and frequency domains
Simulation parameters

Channel:

Modulation and Coding Scheme:
- QPSK
- Rate 1/2, $(171,133)_8$ convolution code

Receiver:
- Theoretical correlation functions for performing LMMSE channel estimation
- Channel estimates used directly in LLR computation
- Soft input Viterbi decoder

\[ \tau_{\text{rms}} = 0.4 \, \mu s \]
Simulation parameters

Channel:

Modulation and Coding Scheme:
- QPSK
- Rate 1/2, $(171,133)_8$ convolution code

Receiver:
- Theoretical correlation functions for performing LMMSE channel estimation
- Channel estimates used directly in LLR computation
- Soft input Viterbi decoder

\[ \tau_{\text{rms}} = 0.4 \mu s \]
FER performance

\[ \nu = 100 \text{ km/h} \]
\[ \tau_{\text{rms}} = 0.4 \mu s \]
\[ M_p = 8 \]
\[ N = 146 \text{ Byte} \]
SF – Standard Frame
MF – Modified Frame
FER performance

\[ \nu = 100 \text{ km/h} \]
\[ \tau_{\text{rms}} = 0.4 \mu s \]
\[ M_p = 8 \]
\[ N = 146 \text{ Byte} \]

SF – Standard Frame
MF – Modified Frame
FER performance

\[ \nu = 100 \text{ km/h} \]
\[ \tau_{\text{rms}} = 0.4 \mu s \]
\[ M_p = 8 \]
\[ N = 146 \text{ Byte} \]

SF – Standard Frame
MF – Modified Frame

**Graph**: FER performance vs. \( E_s / N_0 \) in dB.
FER performance

\[ \nu = 100 \text{ km/h} \]
\[ \tau_{\text{rms}} = 0.4 \mu s \]
\[ M_p = 8 \]
\[ N = 146 \text{ Byte} \]

SF – Standard Frame
MF – Modified Frame
$\tau_{\text{rms}} = 0.4 \ \mu s$

$M_P = 8$
FER performance

\[
\tau_{\text{rms}} = 0.4 \, \mu s \quad M_p = 8
\]
FER performance

\[ \tau_{\text{rms}} = 0.4 \mu s \]
\[ M_P = 8 \]
Linear interpolation

\[ \nu = 100 \text{ km/h} \]
\[ \tau_{\text{rms}} = 0.4 \mu s \]
\[ M_P = 8 \]
\[ N = 146 \text{ Byte} \]

SF – Standard Frame
MF – Modified Frame
Conclusion

• Complementary training symbols can be inserted in the 802.11p frame without modifying the transmitter MAC and PHY layers

• The period of the complementary training symbols can be decided adaptively and indicated in SERVICE field

• Robust channel estimates can be obtained and hence guarantee very low packet error rates with a simple receiver structure

• The complementary training symbols introduce additional overhead

• A simplified receiver structure suitable for hardware implementation is proposed.