COMBINED TIME AND FREQUENCY DOMAIN OFDM CHANNEL ESTIMATION

Maik Bevermeier, Reinhold Haeb-Umbach

Department of Communications Engineering
University of Paderborn, Germany
{bevermeier, haeb}@nt.uni-paderborn.de

ABSTRACT

In Orthogonal Frequency Division Muliplexing (OFDM) a high-rate data stream is transmitted by many low-rate streams in parallel, thus turning a frequency-selective channel into a set of parallel non-frequency selective channels, for which a simple one-tap equalisation can be carried out [1]. In recent years, a lot of different channel estimation techniques have been developed for wired and wireless OFDM systems. In packet-oriented coherent transmission, e.g. in the LAN standards IEEE 802.11a/b/g [2], [3], the physical frame format contains known symbols in the preamble, on which channel estimation can be carried out, and the payload carrying the data. The payload also carries known data on a few subcarriers, called pilots, which usually are needed for frequency synchronisation. Particularly when transmitting with a large payload size or at a high mobile velocity the channel changes significantly during transmission of the payload. For these cases, semi-blind channel estimation has been proposed, where initial channel estimates on the preamble are further improved by reestimation on the data.

Our approach is also based on a combination of an estimation carried out on the preamble and on the payload. However, the combination is achieved in an optimal manner. First, a Kalman Filter is used for estimation of the channel impulse response on the preamble in the time domain. This has been shown to be computationally more efficient and to result in a lower variance of the estimates compared to a frequency-domain Kalman Filter [4].

Next we conduct channel frequency response (CFR) estimation on the symbols of the payload, which consists of two steps. The first step is a Maximum-Likelihood estimation, either solely at the subcarriers of the interspersed pilot data or also on the data subcarriers using the Expectation-Maximization (EM) algorithm [5]. In a second step the estimates are improved by Wiener filtering. Interestingly, the required covariance matrix of the channel frequency response can be obtained as a by-product of the aforementioned Kalman Filter.

By transforming the state vector of the Kalman filter to the frequency domain, we now have two estimates for the channel frequency response: The Kalman filter estimate $\tilde{\mathbf{h}}^{(KF)}$ and the Wiener Filter estimate $\tilde{\mathbf{h}}^{(WF)}$. The optimal combined estimate $\tilde{\mathbf{h}}^{(c)}$ is then obtained as [6]:

$$(\tilde{\mathbf{P}}^{(c)})^{-1}\tilde{\mathbf{h}}^{(c)} = (\tilde{\mathbf{P}}^{(WF)})^{-1}\tilde{\mathbf{h}}^{(WF)} + (\tilde{\mathbf{P}}^{(KF)})^{-1}\tilde{\mathbf{h}}^{(KF)}.$$

Note that the optimal combination requires knowledge of the error covariances $\tilde{\mathbf{P}}^{(KF)}$ of the Kalman Filter, $\tilde{\mathbf{P}}^{(WF)}$ of the Wiener Filter and $\tilde{\mathbf{P}}^{(c)}$ of the combined estimator. But these are readily available as a byproduct of the two Bayesian estimators.

In the simulations we used a frame data structure similar to an IEEE 802.11a systems. A burst consists of $B = 102$ symbols, of which the first two are the known preamble and the remaining form the payload. Of the total of $M = 64$ subcarriers, four channels are reserved for known pilots. The available bandwidth in the 5 Ghz Band is chosen to 20 MHz, the data rate is 24 MBit/s with 96 data bits per OFDM symbol (coding rate $1/2$), and the modulation employed is 16-QAM.

The channel is Rayleigh fading with six independent propagation paths with power loss and delay profile of $[-1, -3, -5, -7, -9, -12]$ dB and $[100, 200, 300, 400, 500, 600]$ ns and Jakes Doppler spectrum, which corresponds to a typical urban type of scenario. For the Kalman Filter design the Jakes Spectrum is approximated by a first-order AR process. The mobile terminal velocity is set to $v = 30.8$ km/h. For the simulations presented in this abstract, the channel model parameters are assumed to be perfectly known.

Fig. 1 shows the mean square estimation error (MSEE) of the CFR estimation and the bit error rate (BER) of the decoder, respectively, for individual and combined estimators. It comes to no surprise that a channel estimation which is based only on the interspersed pilot subcarriers of the payload performs very poorly (curve denoted by “ML-Pilot-WF”), while the time-domain Kalman Filter (“KF”) gives considerably better results. But still, the estimator which combines the two, is noticeably better than the Kalman Filter alone (“(ML-Pilot-WF)+KF”). The frequency-domain estimator is now improved by carrying out an iterative ML estimation on the data carriers employing the EM algorithm. The estimates on the pilot and data subcarriers are then again smoothed by a Wiener Filter and then combined with the Kalman Filter in the aforementioned optimal manner (“(ML-Pilot-Data-WF)+KF”). As can be seen, this results in the overall best MMSE value. The additional BER improvement due to the use of the EM algorithm on the data subcarriers is, however, marginal.

In the full paper we will also discuss the effect of imperfect knowledge of channel parameters and computational issues.

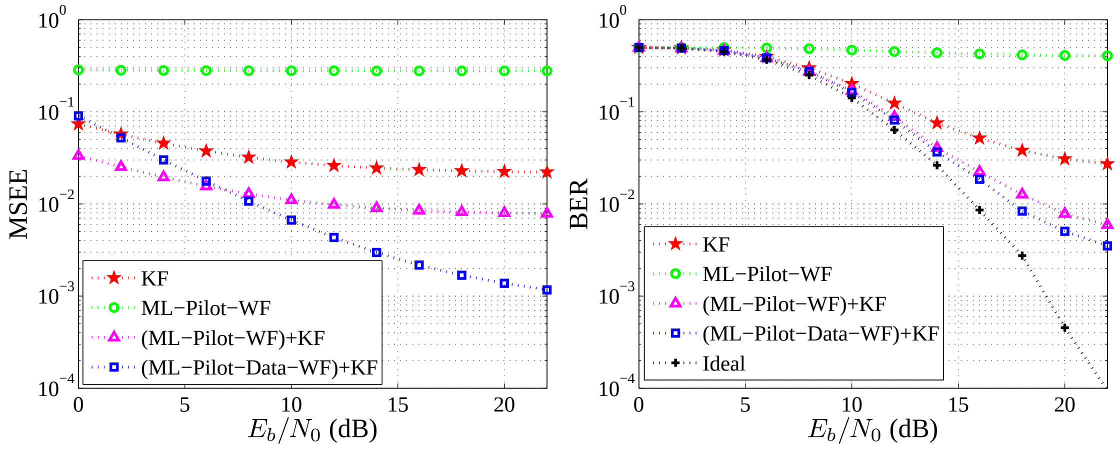

Fig. 1. Combined estimator.

REFERENCES

[1] A. R. S. Bahai, B. R. Saltzberg and M. Ergen, *Multi-Carrier Digital Communications: Theory and Applications of OFDM*, Springer, 2004.

[2] Z. Wang and G. Giannakis, ”Wireless multicarrier communications”, *IEEE Signal Processing Magazine*, Vol. 17, no.3, pp. 29-48, May 2000.

[3] IEEE Std 802.11a-1999, ”Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications - High-speed Physical Layer in the 5 GHz Band”.

[4] T. Roman, M. Enescu and V. Koivunen, ”Time-domain method for tracking dispersive channels in OFDM systems”, in *Proc. IEEE VTC Spring*, Jeju, Korea, 2003.

[5] X. Ma, H. Kobayashi and S. Schwartz, ”EM-based channel estimation algorithms for OFDM”, *EURASIP Journal on Applied Signal Processing*, 2004:10, pp. 1460-1477.

[6] T. Kailath, A. Sayed and B. Hassibi, *Linear Estimation*, Prentice Hall, 2000.