OFDM channel estimation with emphasis on the uplink

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Channels fade in time and frequency

We need to estimate/predict the channel in order to:
- retrieve payload data
- allow for optimal scheduling
Adapting to the short-term fading

Our system allocates time/frequency resources based on channel quality, which enables multiuser diversity gains.

- At time $t$, the quality (SINR) of the fading channel at time $t+L$ must be predicted, for all resources. This is done for each terminal over a large bandwidth.
- A scheduler at the base station allocates resources based on the qualities signalled by the terminals.
The least unit for user resource allocation is called a bin.

- **Pilots (known QPSK symbols)**
- **System data (unknown QPSK symbols)**
- **Payload data (BPSK-256QAM symbols)**

- Use pilots and system data to estimate the channels at these 12 locations/bin.
- To retrieve payload data, fit a smooth surface to the rest of the bin.

It is assumed that QPSK symbols may be correctly detected even when the SNR is low.
Modelling the complex channel on one subcarrier (tap)

\[ x_{n,t+1} = \begin{bmatrix} -d_1 & 1 \\ -d_2 & 1 \\ -d_3 \\ -d_4 \end{bmatrix} x_{n,t} + \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} e_{n,t} \]

\[ h_{n,t} = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix} x_{n,t} \]

The time correlation is described by the \( d_1..d_4, c_1..c_4 \) parameters (4th order AR model)
Time correlation

Doppler spectra for the two different fading models

Either of these is approximated with a 4th order AR model.
Modelling parallel taps on adjacent subcarriers

\[
\begin{bmatrix}
  x_{1,t+1} \\
  x_{2,t+1} \\
  x_{3,t+1} \\
  x_{4,t+1}
\end{bmatrix} = \begin{bmatrix}
  F_{\text{tap}} & F_{\text{tap}} & F_{\text{tap}} \\
  F_{\text{user}} & F_{\text{tap}} & F_{\text{tap}}
\end{bmatrix} \begin{bmatrix}
  x_{1,t} \\
  x_{2,t} \\
  x_{3,t} \\
  x_{4,t}
\end{bmatrix} + \begin{bmatrix}
  G_{\text{tap}} & G_{\text{tap}} & G_{\text{tap}} \\
  G_{\text{user}} & G_{\text{tap}} & G_{\text{tap}}
\end{bmatrix} \begin{bmatrix}
  e_{1,t} \\
  e_{2,t} \\
  e_{3,t} \\
  e_{4,t}
\end{bmatrix}
\]

\[
\begin{bmatrix}
  h_{1,t} \\
  h_{2,t} \\
  h_{3,t} \\
  h_{4,t}
\end{bmatrix} = \begin{bmatrix}
  H_{\text{tap}} & H_{\text{tap}} & H_{\text{tap}} \\
  H_{\text{user}} & H_{\text{tap}} & H_{\text{tap}}
\end{bmatrix} \begin{bmatrix}
  x_{1,t} \\
  x_{2,t} \\
  x_{3,t} \\
  x_{4,t}
\end{bmatrix}
\]

\[
R_e = E\left(\begin{bmatrix}
  e_1 \\
  e_2 \\
  e_3 \\
  e_4
\end{bmatrix} \begin{bmatrix}
  e_1 \\
  e_2 \\
  e_3 \\
  e_4
\end{bmatrix}^*\right)
\]

describes the frequency correlation.
A state space representation for the downlink channel

N parallel tracked subchannels:

\[ x_{t+1} = F_{\text{user}}x_t + G_{\text{user}}e_t \]
\[ h_t = H_{\text{user}}x_t \]
\[ y_t = \phi_t^* h_t + \nu_t \]

where \( \phi_t^* = \begin{pmatrix} s_1 \\ \vdots \\ s_N \end{pmatrix} \)

The Kalman filter produces both \( \hat{h}_{t|t}, \hat{h}_{t+1|t} \) and \( \hat{h}_{t+L|t} \).

\( \phi_t^* \) is known when \( s_1..s_N \) are pilots. When \( s_1..s_N \) are downlink data (unknown) we need to use estimated values:

\[ \hat{s}_{n,t} = \text{detectQPSK}(y_{n,t}/\hat{h}_{n,t|t-1}) \]
Estimating parallel taps

Increasing $N$:

- Increasing filter performance (more frequency correlation is taken into account).
- Increasing computational load on the estimator.
The benefits of increased filter width

The investigated channel is flat fading. Doubling the filter width leads to a 3 dB increase in performance.
What about the uplink?

The downlink enables each user to estimate its own channel. For the uplink, the basestation needs to estimate several channels – one for each user.

We investigate one method of doing this: let all users share the same resource. Users not scheduled for traffic only send pilots. The base station then operates on a superposition of signals (overlapping pilots).
Modelling the superposition

Several users (U) share the same resource.

\[ X_{t+1} = \begin{bmatrix} F_{user} & F_{user} \\ F_{user} & F_{user} \end{bmatrix} X_t + \begin{bmatrix} G_{user} \\ G_{user} \end{bmatrix} e_t \]

\[ h_t = \begin{bmatrix} H_{user} \\ H_{user} \end{bmatrix} X_t \]

\[ y_t = \begin{bmatrix} s_{1,1} \\ \vdots \\ s_{N,1} \end{bmatrix} + \begin{bmatrix} s_{1,U} \\ \vdots \\ s_{N,U} \end{bmatrix} h_t + v_t \]

Note that \( y_t \) still only holds N values (N subchannels)
Performance for many users

Assume unknown QPSK symbols are correctly detected

Number of users < filter width $\Rightarrow$ Little or no loss
Performance for many users

Unknown QPSK symbols are estimated based on estimates of the channel state.

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$\Rightarrow$ Good results even when number of users $> \text{filter width}$
Performance for many users

Unknown QPSK symbols are estimated based on estimates of the channel state.

Good results even when number of users > filter width
Performance for two users with different SNRs

Assume unknown QPSK symbols are correctly detected.

The SNR for user 2 is 3 dB below the SNR for user 1.
Performance for two users with different SNRs

Unknown QPSK symbols are estimated based on estimates of the channel state.

Green : User 1
Red : User 2

The SNR for user 2 is 3 dB below the SNR for user 1
Conclusions

The results show that this choice of design for the uplink is likely to work.

In reality, different users will have different SNRs and channels won’t be flat fading. This will put harder strain on the filter and the effects of it needs to be investigated.