A Hybrid Modulation Scheme for Noncoherently Detected OFDM-MFSK

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Outline

- Motivation
- Basic OFDM Transmission Model
- A Robust Transmission Scheme – OFDM-MFSK
- Increasing the Bandwidth Efficiency using Hybrid Modulation
- Simulation Results
- Conclusions
Motivation

- Scenario: Communication with high speed trains
- Speed up to 600 km/h causes fast changing channels
- Channel estimation is very difficult
- Security relevant control data requires robust transmission
- Additional services for passengers like internet access require high data rates
- FSK schemes are very robust and are currently in use

**Goal:** Robust transmission scheme based on OFDM with high data rate
Basic OFDM Transmission Model

\[ x(k) \]

\[ \tilde{x}(k) \]

\[ h(t) \]

\[ n(t) \]

\[ g(t) \]
A Robust Transmission Scheme – OFDM-MFSK

- Subcarriers are grouped into groups of M and MFSK modulation is applied to each group
- $\log_2 M$ bits can be assigned to each group
- No CSI is needed for noncoherent detection
- Very robust against time variant channels
- Low bandwidth efficiency (uncoded OFDM-4FSK: 0.5 bit/subcarrier)
A Robust Transmission Scheme – OFDM-MFSK

Noncoherent detection
◆ Subcarrier phase of transmit symbols is arbitrary

This degree of freedom can be exploited
◆ Phases can be used for PAPR reduction
◆ Use phases to increase bandwidth efficiency by transmitting additional data
◆ Noncoherent detection of OFDM-MFSK is not influenced
Hybrid Modulation Scheme

- Additional differential encoding of phases of occupied subcarriers
- Encoding in frequency or time direction
- Noncoherent detection, no CSI needed
Channel Coding

- Separate encoding of MFSK and DPSK component
- Detection and decoding of MFSK component first to determine occupied subcarriers
- Afterwards detection and decoding of DPSK component

Advantages:

- Different level of protection for both components using different codes
- Coded OFDM-MFSK transmission is not affected by DPSK component

Convolutional code: rate 1/2, memory 6, generator polynomial [133,171], soft decision detection
Simulation Results – AWGN

Overall BER for uncoded transmission:

![Graph showing BER vs. Eb/N0 for Basic OFDM-MFSK and Hybrid Modulation Scheme]
Simulation Results – AWGN

Overall BER for coded transmission:

- Separate coding for 4FSK and DPSK component using the same convolutional code
- BER is dominated by 4FSK errors for AWGN
- Codes can be adapted
Worst Case Channel Model

- Reflection at tunnel entrance or bridge
- Two paths with equal attenuation
- Maximum Doppler spread $2f_d = 2f_c \frac{v}{c}$ due to opposite direction of arrival

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>carrier frequency $f_c$</td>
<td>38 GHz</td>
</tr>
<tr>
<td>FFT length $N_f$</td>
<td>256</td>
</tr>
<tr>
<td>subcarrier separation $\Delta f$</td>
<td>312.5 kHz</td>
</tr>
<tr>
<td>cyclic extension $T_g$</td>
<td>$N_g \Delta t = 0.8 \mu s$</td>
</tr>
<tr>
<td>no. of used subcarriers $N_{fused}$</td>
<td>160</td>
</tr>
<tr>
<td>symbol duration $T_s$</td>
<td>$(N_g + N_f) \Delta t = 4 \mu s$</td>
</tr>
</tbody>
</table>
Simulation Results

BER for coded OFDM-4FSK:

- Path delay $t_d = 0.75 \mu s$
- Strong frequency selectivity
- Very robust against frequency selectivity
- Very robust against high velocity
Simulation Results

Overall BER for coded transmission:

- **DPSK component encoded in frequency direction**
- **Speed** $v = 600 \text{ km/h}$
- **Very robust against high velocity**
- **DPSK component very sensitive against frequency selectivity (large distance between used subcarriers)**
Conclusions

Conclusions

◆ Noncoherently detected OFDM-MFSK is a robust transmission scheme in fast fading environments

◆ Subcarrier phases can be used for PAPR reduction or transmission of additional data

◆ Hybrid modulation does not affect the underlying MFSK transmission but offers additional data rate for moderate channels

◆ no CSI necessary

Future Work

◆ Adaption of codes for both components

◆ Improvement of robustness against frequency selectivity of DPSK component