OTFS Based Orthogonal Multiple Access (OMA)

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13 March 2023
Outline

- OTFS Modulation
- Resource Element in DD and TF domain
- GB based MA
- Interleaved DD MA (IDDMA)
- Interleaved TF MA (ITFMA)
- SE performance comparison
- Conclusions

Single-antenna multi-user (MU) uplink
Doubly-spread channels
OTFS modulation
OTFS Modulation

- OTFS modulator and demodulator*

- Communication in delay-Doppler (DD) domain

- Robust to delay and Doppler spread compared to OFDM

Resource Element in DD domain

- Carrier: Pulses* on information grid (delay and Doppler spread is $\frac{T}{M}$ and $\frac{\Delta f}{N}$)

- DDRE: DD domain resource element
  - Smallest resource unit
  - 1 DDRE = 1 degree of freedom
  - Total: $MN$ DDREs

Resource Element in TF domain

- Carrier bandwidth*: Inverse of DD pulse delay spread \( \frac{1}{T/M} = M \Delta f \)
- Carrier time duration*: Inverse of DD pulse Doppler spread \( \frac{1}{\Delta f/N} = NT \)
- TFRE: TF domain resource element
  - Smallest resource unit in TF domain
  - 1 TFRE = 1 degree of freedom
  - No. of degrees of freedom: Time-bandwidth product
    \( M \Delta f \times NT = MN \)

Guard-band (GB) based Orthogonal Multiple Access

- Non-overlapping multi-user (MU) resource allocation in DD domain

- Allocated MU resource separated by guard bands (GBs)
- GBs required to reduce MU interference (MUI)
- GBs are an overhead: Do not carry information
GBs along delay domain

- GBs along delay domain
Interleaved DD domain MA (IDDMA)

- Each DD pulse has twice the delay and Doppler spread
- TF signal restricted to \( \frac{1}{2\Delta f/N} \times \frac{1}{2T/M} \) i.e., \( \frac{NT}{2} \times \frac{M\Delta f}{2} \)

Each UT is restricted to non-overlapping TFREs \((\frac{NT}{2} \times \frac{M\Delta f}{2})\)

No guard band overhead
Interleaved allocation in TF domain*
No guard band overhead

Spectral Efficiency (SE) performance comparison

- ETU channel model

<table>
<thead>
<tr>
<th>Path no. $i$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel. Delay $\tau_i$ (µs)</td>
<td>0</td>
<td>0.05</td>
<td>0.12</td>
<td>0.2</td>
<td>0.23</td>
<td>0.5</td>
<td>1.6</td>
<td>2.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Rel. Power $\frac{\mathbb{E}[</td>
<td>h_i</td>
<td>^2]}{\mathbb{E}[</td>
<td>h_1</td>
<td>^2]}$ (dB)</td>
<td>−1</td>
<td>−1</td>
<td>−1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Path Doppler shift: $\nu_i = \nu_{\text{max}} \cos(\theta_i)$, $\theta_i \sim \text{i.i.d. Unif}(0, 2\pi)]$

- Path channel gain: Rayleigh faded, $\sum_{i=1}^{9} \mathbb{E}[|h_i|^2] = 1$

- $\Delta f = 15$ KHz, $T = \frac{1}{\Delta f} = 66.66$ µs

- Avg. Received SNR: Ratio of recv'd. signal power from a UT to noise power at Rx ($M \Delta f N_0$)

- $Q$: No. of UTs, $N = M = 36$

- IDDMA: DD pulse delay domain spread $g_1 T / M$, Doppler domain spread $g_2 \Delta f / N$, $Q = g_1 g_2$

- ITFMA: Repetition factors, $g_3$ along delay domain, $g_4$ along Doppler domain, $Q = g_3 g_4$
$g_1 = g_3 = 3, g_2 = g_4 = 2$

- IDDMA is better than both ITFMA and GBMA

$g_1 = g_3 = 3, g_2 = g_4 = 2$

- IDDMA is more robust to Doppler spread than both ITFMA and GBMA

Why is IDDMA better than ITFMA?

- $g_1 = g_3 = 2$, $g_2 = g_4 = 2$, $\nu_{\text{max}} = 5$ KHz, $M = N = 36$
- Ratio of variance of MUI to that of useful signal in TF domain

Conclusions

- IDDMA is more robust to delay/Doppler spread than ITFMA and GBMA
  - GBMA: No information in guard bands
  - ITFMA: Experiences high MUI from neighbouring TFREs of other UTs
  - IDDMA: Contiguous allocation of TFREs, interior TFREs experience less MUI

- Next possibilities
  - Windowing to reduce the impact of MUI on boundary TFREs in IDDMA
  - Impact of channel estimation errors
Thank you
\[ g_1 = g_3 = 3, \quad g_2 = g_4 = 2 \]

- Small Doppler spread: IDDMA is better than ITFMA which is better than GBMA
• Larger $G \rightarrow$ increase in overhead $\rightarrow$ reduction in SE
Same observations as for $N = 36$
• IDDMA, ITFMA: Sum SE almost constant with increasing $Q$
Impact of delay spread on SE

- IDDMA is more robust to increase in delay spread