## Orthogonal Pilot Design for 16m Uplink PUSC

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## Orthogonal Pilot Design for 16m Uplink PUSC

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## Problem Setup

$>$ The quality of the channel estimation in the uplink is critical to the link performance and overall system throughput.
> There are two problems that impact the quality of the channel estimates:

- A weak signal received at serving sector.
- Presence of interfering users.
> Uplink is interference limited.
- Typically there are two or three dominant interferers.
> We shall focus on improvement in channel estimation in UL-PUSC.


## System Model


> Current IEEE 802.16e/WiMAX standard use a pseudo random binary sequence to randomize the interference.

## System Model

> We shall first consider the case when we have a single dominant interferer from the adjacent sector.
$>$ Signal received at the serving sector on the pilot locations is given by:

- $y_{11}=c^{(1)}{ }_{11} h+c^{(2)}{ }_{11} g+n_{11}$
- $\mathrm{y}_{12}=\mathrm{c}^{(1)}{ }_{12} \mathrm{~h}+\mathrm{c}^{(2)}{ }_{12} \mathrm{~g}+\mathrm{n}_{12}$
- $y_{21}=c^{(1)}{ }_{21} h+c^{(2)}{ }_{21} g+n_{21}$
- $\mathrm{y}_{22}=\mathrm{c}^{(1)}{ }_{22} \mathrm{~h}+\mathrm{c}^{(2)}{ }_{22} \mathrm{~g}+\mathrm{n}_{22}$
where
- $\mathrm{C}^{(\mathrm{k})}{ }_{\mathrm{ij}}$ is the PRBS code of sector k at pilot location ( $\mathrm{i}, \mathrm{j}$ )
- $h$ is the channel of the desired user
- $g$ is the channel of the interfering user
- n is the noise.
> It is assumed that h and g remain constant both across the tones and the symbols of a tile.


## Linear Channel Estimation

> Estimation of the channel of the desired user at the serving sector:

- Multiply the received signal by the PRBS (de-PRBS) sequence of sector 1.
- Average the resulting signal at the 4 pilot locations.
> Thus, with linear averaging, the channel estimate is given by
- $\mathrm{h}_{\mathrm{est}}=\left(\sum_{\mathrm{ij}} \mathrm{y}_{\mathrm{ij}} \mathrm{c}^{(1)}{ }_{\mathrm{ij}}\right) / 4$

$$
=\mathrm{h}+\left[\left(\sum_{\mathrm{ij}} \mathrm{c}^{(1)_{\mathrm{ij}}} \mathrm{c}^{(2)_{\mathrm{ij}}}\right) / 4\right] \mathrm{g}+\left(\sum_{\mathrm{ij}} \mathrm{n}_{\mathrm{ij}}\right) / 4
$$

> The PRBS codes (taking values $\pm 1$ ) are generated independently for the two sectors, thus we have that the channel estimate is given by

$$
\mathrm{h}_{\text {est }}=\begin{array}{ll}
\mathrm{h}+\mathrm{g}+\left(\sum_{\mathrm{ij}} \mathrm{n}_{\mathrm{ij}}\right) / 4 & \text { with probability } 1 / 16 \\
\mathrm{~h}+\mathrm{g} / 2+\left(\sum_{\mathrm{ij}} n_{\mathrm{ij}}\right) / 4 & \text { with probability } 4 / 16 \\
\mathrm{~h}+\left(\sum_{\mathrm{ij}} \mathrm{n}_{\mathrm{ij}}\right) / 4 & \text { with probability } 6 / 16 \\
\mathrm{~h}-\mathrm{g} / 2+\left(\sum_{\mathrm{ij}} \mathrm{n}_{\mathrm{ij}}\right) / 4 & \text { with probability } 4 / 16 \\
\mathrm{~h}-\mathrm{g}+\left(\sum_{\mathrm{ij}} \mathrm{ij}\right) / 4 & \text { with probability } 1 / 16
\end{array}
$$

## Key Idea

- We shall not rely on PRBS to provide us protection against interference.
$>$ We shall use orthogonal codes over pilots to completely cancel out interference.
> Each Sector picks a 4-bit/symbol code word for its pilots from an orthogonal set
$>$ Denote the set of orthogonal codes as the following $4 \times 4$ Matrix

$$
\begin{gathered}
\mathbf{X}=\left[\underline{\mathbf{x}}_{1}, \underline{x}_{2}, \underline{\mathbf{x}}_{3}, \underline{\mathbf{x}}_{4}\right] \\
\underline{\mathbf{x}}_{i}=\left[\begin{array}{llll}
x_{i 1} & x_{i 2} & x_{i 3} & x_{i 4}
\end{array}\right]
\end{gathered}
$$

## Channel Estimation

> The data sub-carriers have the same PRBS as in $16 e$ (no changes as regards to generation of PRBS for data tones). They receive the same amount of "protection" from interference as in earlier cases.
$>$ The received signal $\boldsymbol{y}$ at the pilot locations in sector 1 is given by:

$$
\mathbf{y}=\mathrm{h} \underline{\mathbf{x}}_{1}+\mathrm{g}_{2} \underline{\mathbf{x}}_{2}+\mathrm{g}_{3} \underline{\mathbf{x}}_{3}+\mathbf{n}
$$

where $\mathrm{h}, \mathrm{g}_{2}$ and $\mathrm{g}_{3}$ are the channel from SS1, SS2 and SS3 to sector 1 respectively and $\mathbf{n}$ is the noise at the pilot locations.
$>$ A linear estimate of the channel from SS1 to sector 1 for the tile is given by:

$$
\begin{aligned}
\mathrm{h}_{\mathrm{est}} & =<\mathbf{y}, \underline{\mathbf{x}}_{1}>/ 4 \\
& =<\mathrm{h} \underline{\mathbf{x}}_{1}+\mathrm{g}_{2} \underline{\mathbf{x}}_{2}+\mathrm{g}_{3} \underline{\mathbf{x}}_{3}+\mathbf{n}, \underline{\mathbf{x}}_{1}>/ 4 \\
& =\mathrm{h}+<\mathbf{n}, \underline{\mathbf{x}}_{1}>/ 4 .
\end{aligned}
$$

We have thus managed to completely cancel out the interference from the adjacent sectors resulting in a "cleaner" channel estimate!

## Code Assignment


$>$ Each sector uses a different code word from a set of orthogonal codes
$>$ In the assignment above the 3 sectors of a cell use 3 different codes, namely code word $1\left(\underline{\mathbf{x}}_{1}\right)$, code word $2\left(\underline{\mathbf{x}}_{2}\right)$ and code word $3\left(\underline{\mathbf{x}}_{3}\right)$

## Link-Level Simulation Results 2 Rx BS

## 4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [0] dB



## 4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [3] dB



## 4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [6] dB



## 4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [9] dB



## 4QAM 1/2,Ped B,3 kmph,2 Rx BS,Two Interferers,SIR [3 3] dB



## 4QAM 1/2,Ped B,3 kmph,2 Rx BS,Two Interferers,SIR [3 6] dB



## 4QAM 1/2,Ped B,3 kmph,2 Rx BS,Two Interferers,SIR [6 6] dB



## Link-Level Simulation Results 4 Rx BS

## 4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [-3] dB



## 4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [0] dB



## 4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [3] dB



## 4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [6] dB



4QAM 1/2,Ped B,3 kmph,4 Rx BS,Two Interferers,SIR [0 0] dB


## 4QAM 1/2,Ped B,3 kmph,4 Rx BS,Two Interferers,SIR [0 3] dB



4QAM 1/2,Ped B,3 kmph,4 Rx BS,Two Interferers,SIR [3 3] dB


## 3 Code Arrangement

BTS

## 4 Code Arrangements

> Consider arrangements where all 4 codes of the mutually orthogonal set are used in the network
$>$ There are cells with 3 sectors, thus the basic unit for planning is 4 cells which leads to 12 sectors in total that will share the 4 orthogonal codes.
> Two example uniform 4 code system arrangements shown below.
> Chosen based on the high pilot $\mathrm{C} / \mathrm{l}$ ratio as well as less variation among pilot C/I ratios of 1, 2, 3 and 4 code sectors.
$>$ The basic unit of repetition is shown in red below.

## 4 Code Arrangement 1



## 4 Code Arrangement 2



## Overall Pilot C/I ratio in comparison to 3 code system

Pilot C/I ratio CDF


Note: there is an additional 6dB protection from the PRBS code, thus the actual gain in the channel estimate $C / I$ is 6 dB when using the orthogonal codes.

## C/I ratios of 1, 2, 3 and 4 code users - Arrangement 1

Pilot C/I ratio CDF (Arrangement 1)


## C/I ratios of 1, 2, 3 and 4 code users - Arrangement 2



## Text for the SDD

1. Sectors of a cell in the system shall be assigned an index (4 possible indices)
2. Based on the sector index, each sector of a cell shall use its index to assign its users a code word chosen from a set of orthogonal constellations for use on the pilot tones:
> Data tones in a tile shall use PRBS
> Pilot tones in a tile shall use the orthogonal code word assigned by the sector
3. Orthogonal code words are derived from a set of:
$\rightarrow$ Walsh-Hadamard matrix, or
$>$ Complex 4-QAM ( $\pm 1 \pm \mathrm{j}$ ) constellation
$>$ That are known at the SS receiver
